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BRIDGE ENGINEERING

by

S. C. RANGWALA
B.E. (CIVIL), L.L.B., M.R.S.H. (LONDON)
M.A.C.I. (U.S.A.), M. A S C E (U.S.A.)
M.I.E. (INDIA), M. CONS. E. (INDIA), F.I.V., M.I.S.
Consulting Civil Engineer
Formerly
Lecturer in Civil Engineering
L. D. College of Engineering
AHMEDABAD

Revised and Enlarged
by

K. S. RANGWALA
B.E. (CIVIL), LL.B., A.M.I.E. (INDIA), M.I.C.I.,
Chartered Engineer

and

P. S. RANGWALA
B.E. (CIVIL), A.M.I.E. (INDIA), M.I.C.I.
M. ASCE-IS, A.M.I.V., M. CONS. E. (INDIA)
Govt. Registered and Approved Valuer
Visiting Faculty
School of Building Science and Technology
Centre for Environmental Planning and Technology, AHMEDABAD
Nirma Institute of Technology, AHMEDABAD
Engineering Staff College, AHMEDABAD

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PREFACE

An attempt has been made in this treatise to explain the concepts of Bridge Engineering. The various topics of the subject are explained in simple language with the help of neatly drawn sketches.

The contents of the book are framed by keeping in view the syllabus prescribed by various Universities of India. The book will therefore prove to be useful to students preparing either for Degree or Diploma examinations or for examinations governed by various other professional bodies.

The unique feature of the book is that it is written completely in Metric Units. The subject matter is arranged in proper sequence so as to maintain the continuity of the subject. Typical questions follow each chapter.

I take this opportunity to express my sincere thanks to all good friends who have helped me in writing this book. I am especially grateful to Dr. U.R. Bhatt for his valuable guidance and suggestions. I am also highly grateful to Shri R. C. Patel of Charotar Book Stall, who took keen interest in all aspects of publishing this book. I am also obliged to Anand Press for such decent printing and finishing of the book.

Suggestions to improve the utility of the book will be gratefully received and incorporated in the subsequent editions.

S. C. Rangwala

584, Thengawada
Raipur
Ahmedabad – 1
August 15, 1970

SECOND EDITION

The text of first edition has been exhaustively and extensively revised and new matter is added practically in almost all the chapters to make the book up-to-date.

I take this opportunity to thank all my good friends for sending me their valuable suggestions for improving the text-matter.

It is hoped that the book will become more popular among the student community by the new additions, it now contains.

Ahmedabad – 15
March 24, 1980

S. C. Rangwala

THIRD EDITION

This edition has been thoroughly revised and enlarged. An attempt has been made to make the book up-to-date by adding the substantial new material covering entire syllabus in Bridge Engineering of almost all the Indian Universities as well as Polytechnic Institutions. A good number of examples have been also added at the end of some chapters.

It is hoped that the book should become more popular among the student community by the new additions, it now contains.

Ahmedabad – 15
January 3, 1984

S. C. R.
K. S. R.

SIXTH EDITION

It is indeed a privilege to present this *Sixth Revised and Enlarged Edition* of this popular and highly acclaimed book. The substantial new material and a few questions are added, where necessary, in the respective chapters.

We express our sincere thanks to the teachers for their valuable suggestions as well as the students for their excellent response to this unique book.

The authors would be grateful to the readers of this book to receive their suggestions and comments for further improvement of the book.

Ahmedabad – 380 015
July 11, 1999

S. C. R.
K. S. R.
P. S. R.

SEVENTH EDITION

It is indeed a pleasure to present the *Seventh Edition* of this popular book which provides a unified treatment of the topics on the subject of Bridge Engineering. As this book has now entered in its *Seventh Edition*, proves the appreciation and the popularity of the book by the teachers and the students of almost all the Technical Institutions of our country.

We feel confident that this edition will be of immense use and will assist to both the teachers and the students.

Suggestions to improve the utility of the book are always welcome!

'Sada Mangal'
12, Gokul Park, Polytechnic
Ahmedabad – 380 015
April 25, 2002

S. C. R.
K. S. R.
P. S. R.

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INTRODUCTION

General:

A *bridge* is an arrangement made to cross an obstacle in the form of a low ground or a stream or a river or over a gap without closing the way beneath. The bridges are required for the passage of railways, roadways, footpaths and even for the carriage of fluids.

It is quite evident that the development of the science of bridge engineering has taken place with the development of human civilization. In the beginning, the men used fallen trees or wooden logs to function as the bridges.

The science of bridge engineering developed with varied degrees in different countries. Some of the Roman bridges in Italy are among the fine bridges of the past. In the eighteenth century, France was the most powerful country of continental Europe and because of its prosperity and taste in art, it has produced numerous and the finest bridges during this period. It is really a pleasure to see the existing eighteenth century bridges in France.

The bridge over the river Nile built by Means, the king of Egypt about 2650 BC was the earliest bridge on record. After five centuries, another bridge was built by Queen Semiramio of Babylon across the river Euphrates. The oldest existing arch dating back to about 350 BC and consisting of 20 pointed arches each of 7.5 m span is at Khorsbad in Babylonia.

The earliest construction of permanent bridges started around 4000 B.C. The lake dwellers of Switzerland are said to be the pioneers of timber–trestle construction. The Indians also developed the prototype of the modern suspension bridge at about the same time.

Timber gave place to iron as the building material in eighteenth century. The first iron bridge of 30.5 m span was built in 1779 over the Severn in Coalbrookdale, England. The arch bridges were developed simultaneously by the Romans and Chinese.

The Roman arch bridges date back to 200 B.C. The Chao–Chow bridge situated at a distance of about 350 km from Beijing is supposed to be built around 600 A.D. and is perhaps the longest lasting single span of 37.4 m vehicular bridge at present.

The coming up of railways in the nineteenth century completely changed the concept of bridge engineering. The immense technical progress in the bridge engineering took place during this period and the bridges assumed the form of structures with designed loads.

At present, the bridge engineering has become a specialized subject by itself. Following are the important factors which are responsible for putting the subject of bridge engineering on the scientific footing:

(1) advances made in other branches of engineering such as hydraulics, soil mechanics, structural engineering, etc.;
(2) advent of new materials of construction;
(3) concept of new design ideas in theory;
(4) improvement in the methods of construction;
(5) increase in loads of railways and highways; etc.

In the chapters to follow, an attempt will be made to explain the basic concepts of the bridge engineering.

Development of bridges:

The primitive and prehistoric man had non–vegetarian habits. He used to live on prey of animals. He was always in search of food and shelter. Early morning, he would leave his abode in search of food and by evening, he used to come back with his prey, roast it and share it with his wife. By going out every morning and coming back every evening, he made a narrow way known as the *field–path*. With the passage of time, the traffic necessitated the development of good earth roads; and as more time passed, the road bridge was constructed where a road came across a stream or a river. It is therefore understood that the bridges were probably the first structures constructed by the human beings. Thus, the development of the bridge construction is closely associated with the history of human civilization.

The exact period of development of bridges in different countries of the world cannot be accurately predicted. But it can be safely said in general that the development of bridges was rapid in some countries, while it was lagging in some other underdeveloped countries.

The development of bridges of the following *four* main types can be put in the diagrammatic forms as shown in charts of fig. 1–1 to fig. 1–4:

CHART SHOWING DEVELOPMENT OF ARCH BRIDGES

Natural rock arches ↓ Corbelled arches ↓ True arches ↓

Natural stepping stones ↓ Artificial stepping stones ↓ Stone slabs on stepping stones or rough piers ↓ Stone beam bridges ↓ Stone cantilever bridges ↓

↓

Masonry arch bridges

↓

R.C.C. arch bridges | Steel arch bridges

FIG. 1–1

CHART SHOWING DEVELOPMENT OF SUSPENSION BRIDGES

Monkey–trains, over–hanging branches and creepers

↓

Rope bridges

↓

Suspension bridges

FIG. 1–2

CHART SHOWING DEVELOPMENT OF SIMPLY SUPPORTED BRIDGES

Simply supported construction

↓

Continuous construction

↓

Cantilever construction ↓ Combinations of cantilever and continuous constructions

Rigid frames

FIG. 1–3

CHART SHOWING DEVELOPMENT OF TRUSS AND GIRDER BRIDGES

Accidentally fallen trees
↓
Purposely felled trees
↓
Two or more felled trees and transverse platform
↓
Timber beams on stepping stones or rough piers
↓
Timber beam bridges on timber piles or crib piers
↓

- ↓ Timber cantilever bridges
- ↓ Timber truss bridges
  ↓
  Steel truss bridges
- ↓ Cast–iron beam bridges
  ↓
  Plate girder bridges
  ↓
  R.C.C. girder bridges
  ↓
  Prestressed cement concrete girder bridges

FIG. 1–4

(1) Arch bridges (fig. 1–1)

(2) Suspension bridges (fig. 1–2)

(3) Simply supported bridges (fig. 1–3)

(4) Truss and girder bridges (fig. 1–4).

It is quite evident that the idea of developing a particular type of bridge came to man by observing many such instances of natural behaviour. The natural rock or caves or steps formed by erosion of the loose soil ultimately led to the concept of arch bridges as shown in chart of fig. 1–1.

It was observed that even monkeys form the monkey–trains, one monkey linking with another for getting across a long gap over the tree–tops. The suspension bridges are nothing but a development of the monkey–trains or connecting together creepers hanging from trees for crossing, as shown in chart of fig. 1–2.

The development of simply supported bridges is shown in chart of fig. 1–3.

The tree which fell down accidentally across a stream is understood to be the earliest example of beam or girder type bridge and ultimately, the truss and girder bridges were developed as per sequence shown in chart of fig. 1–4.

The most common naturally available materials used in the early stages of bridge construction were timber and stone. It is not possible at present to find traces of the ancient bridges constructed of timber because it is a perishable material. However, some traces of old bridge structures made of stone can be found all over the world, mostly in the form of arches, because the stone is fairly indestructible. During the late eighteenth century or so, the timber bridges were covered by suitable material to give them protection against weather. Then, the cast–iron substituted timber or stone and the first cast–iron railway bridge was built by George Stephenson in 1823 on the Stockton–Darlington railway line. This material was again replaced by wrought–iron and then by mild steel.

The introduction of steel in bridge construction gave ample opportunities for designing and forming various forms of efficient steel trusses and many important bridges of the world were constructed of steel trusses of different patterns. The steel cantilever bridge over river Hoogly at Calcutta, constructed in 1943 with a main span of 457 m, is considered to be one of the longest cantilever bridge in the world.

The inventions of reinforced cement concrete or R.C.C. and pre–stressed cement concrete have given a wide field to these materials in bridge construction because of the fact that they can be moulded with confidence in any architectural form. Practically, all the important bridges at present are constructed in almost all the countries of the world with R.C.C. or pre–stressed cement concrete. The latest entrants in the field of bridge engineering are the steel box girder and cable–stays.

In India, the earliest major bridges were built as part of the railway system. The British Engineers made good use of the cast–iron and wrought–iron particularly for long spans and for bridges in the Indo–Gangetic plain. They also relied on local materials such as brick and stone. They constructed a large number of arch bridges which are still in workable condition even though there has been considerable increase in the wheel load passing over the bridges. The iron bridges built by the British Engineers have since been re–built particularly the superstructure portion.

The need for the development of roads was felt in India in the early part of twentieth century and the government focussed its attention for the construction of road bridges. By this time, the concrete has come up as a versatile construction material and hence, the road engineers went in more for either arch or R.C.C. bridges.

The pre–stressed concrete came up in the early forties of the century and in India, the railway and road engineers started to make use of this versatile material in the construction of bridges. The first pre–stressed concrete bridge was built by the Indian Railways near Siliguri on the Assam Rail Link project. Similarly, the first pre–stressed road bridge in India was built across river Palar near Madras. The Indian road engineers have better knowledge of this material and they are able to build pre–stressed concrete bridges with spans upto 140 m.

The construction of third Godavari Railway Bridge is perhaps the only bridge of its kind in the world where bow–string arch girder using concrete has been constructed for a long span of 97.55 m, which clearly shows that the Indian engineers are not lagging behind the bridge engineers in more advanced countries. Another finely executed long span bridges are Brahmputra Bridge at Tezpur, 5.575 km long Mahatma Gandhi Setu across the Ganga near Patna and cable–stayed bridge at Calcutta. The Railway Engineers, on the other hand, are not so enthusiastic about this material and it is understood that the longest pre–stressed concrete bridge on the Indian Railways has span of only 24 m.

Changing Scenario in Design and Construction of bridges:

The trends in the design and construction of bridges have been changing from time to time. They depend upon the following factors:

(i) advancement of design concepts and technology;

(ii) awareness of environmental influence on the behaviour of materials, etc.;

(iii) changing attitudes towards aesthetics in bridges;

(iv) increasing knowledge of the properties and behaviour of new materials;

(v) changing requirements of traffic and communication; and

(vi) improvement in various construction techniques.

The new trends in the design of bridges are sophistication and very accurate analysis. The need of sophistication has arisen because of the following factors:

(i) Availability of Computer Aided Design (CAD) for quick and accurate analysis;

(ii) Efforts to make maximum use of local resources with appropriate technology;

(iii) Increasing awareness of durability, serviceability and constructibility, inspection and maintenance, aesthetics and quality assurance;

(iv) Increasing knowledge of other forces acting on structure which very much affect the analysis and design;

(v) Use of new materials having high strength; and

(vi) Use of very large spans.

With the help of computer, it is now possible to design many complex structural forms for different load combinations. This has resulted in the better analysis of structures. The properties of materials are also known better and hence both the things have allowed engineers to adopt higher stress in materials and to reduce overall margin for safety. Another major change in design of bridges is the adoption of limit state concept instead of working stress concept.

The two notable developments in bridge construction techniques are:

(i) use of cantilever construction method; and

(ii) use of push launching of the entire superstructure.

Several bridges have been designed and constructed in India with the help of these techniques.

Classification of bridges:

The bridges can be classified by many ways with respect to a particular quality or condition. Following are such various classifications of the bridges:

(1) According to the flexibility of superstructure, the bridges are classified as fixed–span bridges or movable bridges.

(2) According to the position of bridge floor relative to the formation level and the highest flood discharge, the bridges are classified as deck bridges, through bridges or semi–through bridges.

(3) According to the interspan relations, the bridges are classified as simple, continuous or cantilever bridges.

(4) According to the form or type of superstructure, the bridges are classified as arch, bow–string girder, rigid frame or suspension bridges.

(5) According to the materials of construction used for superstructure, the bridges are classified as cement concrete, masonry, steel or timber bridges.

(6) According to the method of clearance for navigation, the bridges are classified as bascule, cut–boat, lift, swing or traversing bridges.

(7) According to the expected utility period of service, the bridges are classified as temporary or permanent bridges.

(8) According to the function, the bridges are classified as road, railway, road–cum–railway or pipe–line bridges.

(9) According to the method of connections adopted, the steel bridges are classified as riveted, welded or pin–connected bridges.

(10) According to the length of span, the bridges are classified as culvert, minor, major or long span bridges.

(11) According to the degree of redundancy, the bridges are classified as determinate or indeterminate bridges.

(12) According to the level of crossing of highways and railways, the bridges are classified as over bridges or under bridges.

(13) According to the alignment, the bridges are classified as straight or skew bridges.

(14) According to the loadings, the road bridges and culverts are classified by the I.R.C. as Class AA, Class A and Class B bridges.

It is thus seen that the bridges can be classified in a number of different ways. The classification of bridge with reference to the size has been done differently in our country by the road and rail engineers. According to the road engineers, the bridges are classified on the basis of lineal waterway as follows:

(1) Culverts ... Upto 6 m.

(2) Minor bridges ... 6 m to 30 m.

(3) Major bridges ... Over 30 m.

According to the Indian Railways, the bridges are classified as follows:

(1) Major bridges ... Total waterway more than 18 m or having any span of clear waterway of 12 m or over.

(2) Minor bridges ... Total waterway less than 18 m or having any span of clear waterway less than 12 m.

(3) Important bridges ... Those major bridges having total waterway of 18 m and more; or more than 110 m^2.

The cross-drainage structures for the purpose of investigation are grouped into the following *three* categories in our country:

(1) Culverts and minor bridges having lineal waterway upto 30 m.

(2) Major bridges having lineal waterway exceeding 30 m but on stable rivers and canals.

(3) Important bridges having lineal waterway exceeding 30 m but on major rivers or tributaries which are shifting in nature or which present some problems of stability.

Importance of bridges:

The bridges serve as the most useful links on the land connecting big towns and cities and hence, in case of war or calamities, the destruction of bridges stops the mobility of army or essential goods. The site of a bridge should therefore be properly selected with respect to strategic considerations and all proper precautions and measures should be taken to maintain the bridges in the perfect working order.

The subject of bridge engineering is given special attention during the course of military training due to the fact that the army should be capable of putting quickly the new bridges while advancing and of destroying the existing bridges while retreating.

The construction of bridge in a road or rail project is the costliest part and hence, it calls for the utmost economy. It takes the longest time for completing and requires careful planning, considerable amount of forethought and detailed study of various aspects.

It may also be noted that the bridges across rivers and streams are the most vulnerable because any major damage to the structure can completely upset the total communication system.

It is for this reason that no undue risk can be taken in their design and construction. The economy in bridge construction as well as its long life can be successfully achieved only by the use of proper materials, effective supervision and economic method of construction.

Identification of bridges:

To have the uniform policy of numbering the cross–drainage works along a highway, the Indian Roads Congress have prepared the code IRC: 7–1971 for identifying or numbering the culverts and bridges. According to the provisions of this system, the culverts and bridges on a road are numbered in serial order, the number being expressed as a fraction. The numerator of the number indicates the kilometre in which the structure is situated and the denominator indicates the kilometre–wise serial number of the structure.

For instance, the fourth cross–drainage structure in ninth kilometre (i.e. between kilometre stones 8 and 9) will be designated as 9/4. The number of the structure is inscribed near the top of the left hand side parapet wall as seen by the road users in the end elevation when approaching the structure from each direction. For structures having railings without parapet walls, separate pillars are constructed to inscribe the structure number. If any new culverts are to be introduced between any two existing ones, say between 4th and 5th culverts in km 30 (i.e. between kilometre stones 29 and 30), then the new culverts will be designated as $\frac{30}{4-1}$, $\frac{30}{4-2}$, etc.

The above practice of identification of bridges developed by the specifications and standards committee of the Indian Roads Congress has proved of great help to the staff employed for the maintenance and inspection of bridges.

Preliminary data to be collected:

The careful investigation at the preliminary stage avoids many expensive errors at a later stage. Hence, the investigation process should be carried out diligently and with extreme care to avoid the occurrence of serious mistakes in the bridge project. Following data should be collected and suitably analysed by the engineer–in–charge of the investigation of a bridge site:

(1) availability of electric power;
(2) availability of materials of construction;
(3) availability of skilled and unskilled labour for different jobs of bridge construction;
(4) characteristics and hydraulic data of stream or river;
(5) details of public utility services such as telephone cables, water supply lines, etc. to be accommodated in the bridge cross-section;
(6) details of the existing bridges on the same river;
(7) facilities required for housing labour during the bridge construction;
(8) location of the nearest G.T.S. bench mark with its reduced level;
(9) means of transport to carry the materials;
(10) name of the river and location of the bridge site;
(11) nature of road traffic at the bridge site;
(12) navigational requirements;
(13) need for large scale river training works;
(14) possibility of earthquake disturbances;
(15) present and future traffic;
(16) reasons for constructing the bridge;
(17) safety and aesthetic considerations;
(18) subsoil conditions; etc.

Selection of bridge site:

Following are the factors to be carefully considered while selecting the ideal site for a proposed bridge:

(1) Connection with roads
(2) Firm embankments
(3) Foundations
(4) Materials and labour
(5) Right-angle crossing
(6) Straight stretch of river
(7) Velocity of flow
(8) Width of river.

Each of the above factor will now be briefly described.

(1) *Connection with roads:* The bridges are constructed to connect the roads on either side of a river. The bridge site should therefore form a proper link between the roads on either side of a river. The bed of approaches connecting ends of bridge with the roads should be dry and hard. The approaches at the bridge site should be such that they do not involve heavy expenditure. The approaches should avoid the cutting across the built–up area or religious structures because the acquisition of the land and structures will be expensive, time–consuming and sometimes may cause social problems.

(2) ***Firm embankments:*** The embankments on the upstream side and downstream side of bridge site should be firm, high, permanent, solid, straight and well–defined. Such embankments are not disturbed at the time of heavy floods and they do not allow the course of river to alter.

(3) ***Foundations:*** The nature of soil at the bed of river at bridge site should be such that good foundations are available at reasonable depths for the substructures of bridge. The site subject to minimum scour should preferably be chosen.

(4) ***Materials and labour:*** The site of the proposed bridge should be so located that the materials and labour required for the construction of bridge are easily available. The transport charges for materials and labour at the bridge site should be minimum.

(5) ***Right-angle crossing:*** At bridge site, the direction of flow of water should be nearly perpendicular to the centre–line of bridge. Such a crossing is known as the *right–angle crossing* or *square crossing* or *normal crossing* and it is desirable to have such a crossing as far as possible because of the following facts:

(i) It grants a smooth flow of water.

(ii) It permits the construction of segmental wing walls and return walls with minimum sharp angled structures and thereby, the formation of eddies and cross currents are avoided.

(iii) It provides the shortest length of the bridge span as well as the length of the pier and abutments.

The *skew* or *slanting bridges* are not desirable and they are usually avoided for the following reasons:

(i) It is difficult to construct the skew bridges, especially the skew arch bridges.

(ii) The depth of bridge foundations is likely to be more as the foundations are to be subjected to the scour.

(iii) The design of skew bridges is complicated.

(iv) The maintenance of skew bridges is difficult.

(v) The passage of water under the skew bridges is not smooth and whirls or currents are produced.

(vi) The piers of the skew bridge have to resist excessive water pressures.

(6) ***Straight stretch of river:*** The river should have a straight stretch over a reasonable long distance on the upstream side and downstream side of the bridge site. Such a straight stretch of river ensures smooth and uniform flow of water and it allows smooth navigation. The curved stretch of river is not desirable as it creates problems during construction and maintenance of the bridge.

(7) ***Velocity of flow:*** It is very important to check that the velocity of flow at bridge site is proper. If velocity of flow is less than a particular value, the *silting* will occur and on the other hand, if it is more than a particular value, the *scouring* will occur. As a matter of fact, the velocity of flow at bridge site should be between the range of non–silting and non–scouring velocities. The permissible velocity depends on the nature of bed of river. Table 1–1 shows the permissible velocities for different types of beds of river.

TABLE 1–1
PERMISSIBLE VELOCITIES AT BRIDGE SITE

No.	Nature of bed of river	Permissible velocity in cm per second
1.	Very fine sand	60 to 90
2.	Fine sand and loose clay	Upto 50
3.	Coarse sand	50 to 100
4.	Fine gravel, sandy or stiff clay	100 to 150
5.	Clay with sand	150
6.	Clay	200
7.	Soil with rock and coarse gravel	150 to 250
8.	Rock and boulders	250 to 500

(8) ***Width of river:*** It is quite evident that the width of river indicates length of bridge. It is desirable to have minimum width of river at the bridge site. The smaller the width of river, the cheaper will be the bridge.

The conditions stated above are for an ideal site of a bridge. But in practice, it is difficult to obtain a site which will fulfil all these conditions. Hence, every case has to be studied independently and out of a number of alternatives, that site is to be recommended which satisfies most of the conditions for an ideal site. In this connection, the best guide would be the study of particulars of the existing bridges on the same river especially with respect to the foundation details, clearances, physical features, etc.

It will also be interesting to make enquires about the bridges that have been overtopped or breached since their construction or any other type of failure of the bridge. For bridges of small magnitude, it would be reasonable to study particulars of such bridges within a radius of about 10 km. But for larger bridges, it would be appropriate to collect the particulars of bridges situated at a distance of about 50 km to 60 km.

Stages of investigation:

The investigations for important or very major bridges are carried out in the following *three* stages:

I. Reconnaissance or technical feasibility stage.

II. Preliminary or techno–economic feasibility stage.

III. Detailed survey and project report stage.

It is necessary to see that a near ideal bridge site is chosen and various factors are studied during the investigations in each of the above stage. The data to be collected and the importance of each of the above stage of investigation will now be briefly described.

I. Reconnaissance or technical feasibility stage: In this stage, the entire length of the river within the area to be interconnected has to be studied so as to find out a number of probable sites satisfying the various considerations for locating a bridge. The number of factors satisfied by each site are noted and those sites which satisfy most of the favourable factors are selected for further consideration in the next stage.

The factors to be studied in this stage can be mentioned as follows:

(1) estimating the benefits that will accrue from the likely traffic to pass over the bridge;

(2) gathering data about the behaviour of the river at such sites by studying the available reports;

(3) holding discussions with local knowledgeable people;

(4) making an assessment of construction problems;

(5) studying the existing pattern of traffic;

(6) study of available maps;

(7) visits to the various possible sites so as to understand the local features; etc.

It should be possible at this stage to narrow down the choice to three or four alternative sites for the proposed bridge.

II. Preliminary or techno-economic feasibility stage: In the second stage, an attempt is made to bring out in full detail the comparative merits and demerits of the various alternative sites which are considered feasible in the first stage. The study of such a table would help in choosing the best site of the bridge. It is also necessary to work out the estimated costs of various alternative sites and such estimation should be done carefully so that the final cost may be within a range of plus or minus 15 per cent of the final cost. For this purpose, some minimum field measurements are taken and detailed study of maps of the area is made.

The details to be obtained for each site should be tabulated with respect to the following aspects:

(1) construction and maintenance problems;
(2) distance from important city or town;
(3) expected duration of construction;
(4) length of approaches;
(5) length of bridge;
(6) nature of flow at site;
(7) nature of foundation strata;
(8) rate of return or benefit cost ratio;
(9) saving in detours involved, if any;
(10) total construction cost of bridge;
(11) volume of anticipated traffic; etc.

Depending upon the length of the river to be covered, the techno-economic feasibility study can generally be completed in a period of about 4 to 5 months.

III. Detailed survey and project report stage: Out of possible alternatives, the final selection of bridge site is made and in this stage, full investigations with respect to all the items are carried out for the selected site. The detailed studies are made for ground survey, hydrological data, soil exploration, period of construction, volume of traffic, structural design, detailed estimate, return on investment, construction schedule, etc.

Finally, the project report containing large number of drawings and necessary details is prepared in such a shape that the sanction to the project can be issued; funds can be allotted; field organization can be set up; and the work regarding the preparation of tenders can be immediately started.

In case of very major bridges, it is necessary to carry out the model studies because it is difficult to predict the behaviour of the river after a structure is put up across it. A scale model prepared in a hydraulic research station is helpful in forecasting the behaviour of the river due to the obstructions caused by the embankment on either side and by the piers.

The river behaviour is dependent on many imprecise variables and the experiments on the model are conducted to arrive at the best and most economical combination of the waterway and the protective measures.

Depending upon the time required for completing a model study and for carrying out the detailed soil–boring tests, the time required for the project report preparation will be about 15 to 24 months.

Alignment:

After the site of bridge is decided, the next step is to set out or align the centre–line of bridge. Following aspects of the bridge alignment should be carefully studied:

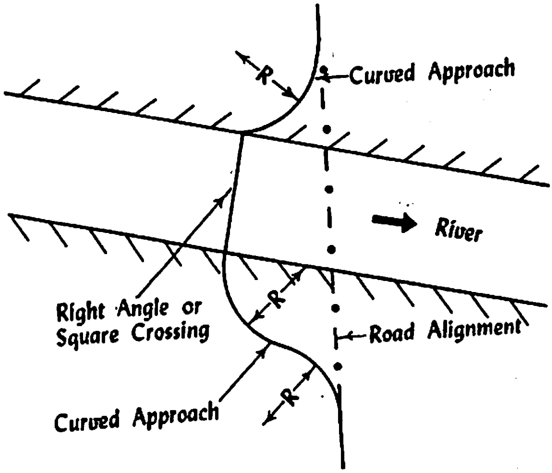
(1) Alignment on curve
(2) Control of highest flood level
(3) Effects of silting and scouring
(4) Layout of approaches
(5) River training works
(6) Skew bridges.

(1) ***Alignment on curve:*** In hilly areas, it is not possible to avoid the alignment of bridge on a curve. In such cases, it is necessary to adopt R.C.C. or steel girders for the superstructure and it should be seen that the axis of each pier is nearly parallel to the centre–line of river.

(2) ***Control of highest flood level:*** The highest flood level or H.F.L. of river plays a great role in fixing the height of bridge. It is possible to control H.F.L. either by diversing the extra flood water or by constructing a storage reservoir on upstream side of the river. It is found that with controlled H.F.L., the design of bridge with adverse alignment can be accurately made.

(3) ***Effects of silting and scouring:*** The necessary precautions should be taken along the bridge alignment to bring down the effects of silting and scouring to the minimum possible extent.

(4) ***Layout of approaches:*** If the existing road alignment is such that it results in an inclined alignment, the curved approaches may be adopted, as shown in fig. 1–5, to form right–angle or square crossing. The layout of approaches is made with suitable curve radii so as to cause the least inconvenience to the traffic using such approaches.



Layout of approaches
FIG. 1–5

(5) ***River training works:*** If necessary, the river training works should be carried out to form what are known as the nodal points i.e. points of minimum displacement in a system of stationary waves, along the bridge alignment. A nodal point is defined as the location where the river regime does not normally shift. The natural nodal points are established by the river flow over the years. The channels of the river shifting its course at the nodal points will be minimum and thus, the stability of the structure is insured. For this purpose, it is desirable to carry out experiments on the models to decide exactly the location of artificial river training works along the river.

(6) ***Skew bridges:*** As far as possible, the skew bridges should be avoided. However, if it is not possible to adopt the right–angle crossing, great care should be taken in the design and execution of skew bridges. The analysis and design of a skew bridge, especially when the skew angle is more than 15°, are more complicated and rigorous than those of a right–angled bridge. The conditions which force the adoption of skew bridges are excessive cost of land, acquisition for approaches, existing road alignment, length of bridge, nature of flow, importance of bridge, etc.

Following *four* precautions should invariably be taken in the design of skew bridges:

(i) It is preferred to arrange the piers parallel to the axis of river.

(ii) The entry and exit of water below the skew bridge should be smooth.

(iii) The skew alignment should not be curved as it is difficult to construct and maintain the curved bridge. The additional force due to the centrifugal action will come into play in case of the curved bridge.

(iv) The skew should be restricted to 30°.

Traffic requirements of highway bridges:

Following are the requirements of traffic which are to be considered in the design of highway bridges:

(1) Alignment
(2) Central verge
(3) Footpath
(4) Lighting
(5) Parapets and handrails
(6) Roadway width
(7) Safety kerbs
(8) Sight distance.

(1) *Alignment:* The sitting or location of the bridge should fit in with the general road alignment. It may require the adoption of skew bridges. It is the general practice to adopt the skew bridges of small angle for small bridges and to adopt square crossings with suitable approaches for long bridges.

(2) *Central verge:* In the interest of safety and traffic flow, it sometimes becomes desirable to segregate or separate traffic of *two* directions by the provision of a central verge. The width of this strip should be kept low from the economic point of view. But it should not be less than 1200 mm.

(3) *Footpath:* The provision of footpaths on either side of bridge will make the movements of pedestrians safe on the bridge and it will result in the reduction of fatal accidents on the bridge. The width of footpath will be decided by the volume of pedestrian traffic and importance of the bridge. For rural areas, the minimum width of footpath should be kept as 1500 mm and it should be suitably increased in the case of urban areas. The capacity of 1500 mm wide footpath can be taken as 108 persons per minute and it should be increased at the rate of 600 mm for every additional capacity of 54 persons per minute.

(4) ***Lighting:*** The lighting on bridge should be carefully designed with respect to distance between adjacent posts, height of post, surrounding environment, importance of bridge, etc.

(5) ***Parapets and handrails:*** The provision of solid parapets or handrails should be made on either side of the bridge to grant safety to the bridge users and to define the width of bridge.

(6) ***Roadway width:*** The minimum roadway widths required for vehicular traffic and cycle tracks are mentioned in table 1–2.

TABLE 1–2
ROADWAY WIDTHS

No.	Type of traffic	Minimum width in cm
1.	Vehicular traffic	
	(i) Single lane bridge	425
	(ii) Two–lane bridge	750
	(iii) Multi–lane bridge	350 for every additional lane over two lanes
2.	Cycles	
	(i) Without overtaking	200
	(ii) With overtaking	300

The highway bridges are designed as one–lane, two–lane or multiple of two–lanes. The required roadway width can be decided from the following considerations:

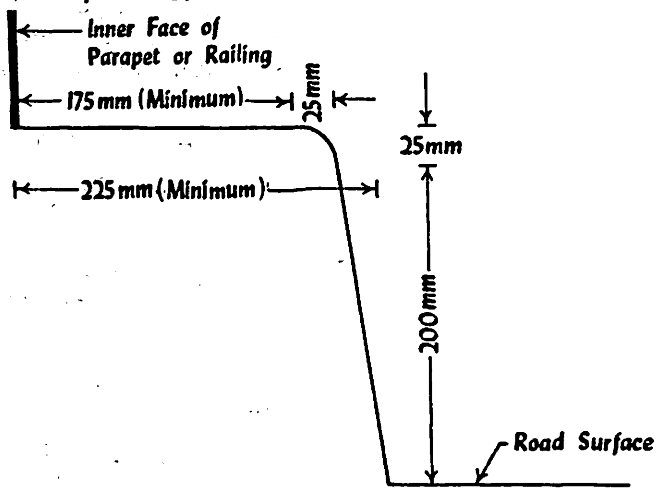
(i) Vehicles : 1000 vehicles per hour per lane width of 3750 mm.

(ii) Cycles : 3600 cycles per day for two–lane (2000 mm).

(7) ***Safety kerbs:*** It is desirable to provide a safety kerb of size about 600 mm × 225 mm on either side of the roadway. A typical section of safety kerb is shown in fig. 1–6.

(8) ***Sight distance:*** The provision of enough sight distance on the highway bridges will ensure the stopping of vehicles without collision. It is measured between points 1200 mm above the roadway along the centrelines of both

the nearside and offside lanes of the bridge. It should be seen that the sight distance is not reduced below the minimum limit due to obstructions such as shrubs, piers, abutments, etc. This precaution is necessary especially in case of underpasses.



Safety kerb
FIG. 1–6

Table 1–3 shows the stopping distances for different class of roads with different design speeds.

TABLE 1–3
SIGHT DISTANCE

No.	Type of road	Design speed in km p.h.	Stopping distance in m
1.	Village roads	50	60
2.	Other district roads	65	80
3.	Major district roads	80	110
4.	National and state highways	100	150

Waterway of a bridge:

The most important factor to be decided in the design of bridges is the determination of the waterway required for the bridge or culvert. The area under a bridge through which the water flows is called the *natural waterway of a bridge*. For important and big bridges, it should be designed to carry water at the time of maximum flood discharge.

Following is the relation between waterway, maximum flood discharge and permissible velocity:

$$A = \frac{Q}{V}$$

where A = Waterway in m^2

Q = Maximum flood discharge in m^3 per second

V = Permissible velocity in m per second.

The lineal waterway is obtained as follows:

$$L = \frac{A}{d}$$

where L = Length of waterway

d = Average depth of water at bridge site.

The value of lineal waterway so obtained is provided under a bridge. If piers or intermediate supports are provided for the bridge, the sum total of spans between successive supports should be equal to the lineal waterway. The natural waterway is thus the total of lineal waterway and widths of supports of bridge.

To work out waterway of a bridge, it is necessary to arrive at a suitable value of maximum flood discharge of the river. We will now briefly discuss the methods of determining or calculating the maximum flood discharge of the river.

Maximum flood discharge: avg of both

[Wherever possible, the maximum flood discharge at bridge site is found out from at least *two* different methods and the higher of the *two* values is adopted as the discharge for designing the bridge. If the value by *two* different methods differ by more than 50% the maximum design discharge is limited to 1.5 times the lower estimate. This is due to the fact that from point of view of economy, it is not desirable to design the bridge for flood of extraordinary high intensity which will rarely occur due to reasons such as failure of dam or tank on the upstream side of bridge site.]

It is considered reasonable to design bridges for floods occurring once in 100 years and to design culverts for floods occurring once in 20 years. The design aspects should however ensure that the likely damages due to rarer floods are brought down to the minimum possible extent.

Following are the *two* methods of calculating the maximum flood discharge:

(1) Direct method

(2) Indirect method.

The salient features of each of the above method will now be briefly described.

Average area of cross-section $= \dfrac{A_1 + A_2 + A_3}{3}$

Measurement of velocity of flow: The velocity of flow is measured by one of the following methods:

(a) by application of Chezy's formula, or

(b) by direct observation.

(a) By application of Chezy's formula:

According to Chezy's formula,

$$v = C\sqrt{m\,i}$$

where v = Velocity of flow in m per second

C = Chezy's constant

m = Hydraulic mean depth

i = Slope of hydraulic grade line.

The above formula was given by French engineer Chezy in 1775. Following points should be noted:

(i) For finding out the value of m, let m_1, m_2 and m_3 be the respective hydraulic mean depths and P_1, P_2 and P_3 be the respective wetted perimeters of cross-sections 1–1, 2–2 and 3–3, as shown in fig. 1–7 and fig. 1–8.

Then, $m = \dfrac{m_1 + m_2 + m_3}{3}$

where $m_1 = \dfrac{A_1}{P_1}$

$m_2 = \dfrac{A_2}{P_2}$

$m_3 = \dfrac{A_3}{P_3}$

(ii) The slope of hydraulic grade line or hydraulic gradient, as it is called, is obtained as follows:

$$i = \frac{D}{3200}$$

where D = Difference in levels between upstream and downstream sections 2–2 and 3–3. Refer fig. 1–7.

(iii) Chezy's constant is very complex and its value can be obtained either by Kutter's formula or Bazin's formula.

Kutter's formula:

$$C = \frac{23 + \frac{0.00155}{i} + \frac{1}{N}}{1 + \frac{N}{\sqrt{m}}\left(23 + \frac{0.00155}{i}\right)}$$

where N is called the *rugosity factor* or *roughness coefficient* and its value varies from 0.02 to 0.03, depending on the condition of bed and sides of river.

This formula was given by Kutter in 1869.

Bazin's formula:

$$C = \frac{157.6}{1.81 + \frac{k}{\sqrt{m}}}$$

where k is Bazin's constant and its value varies from 1.54 to 3.17, depending on the condition of bed and sides of river.

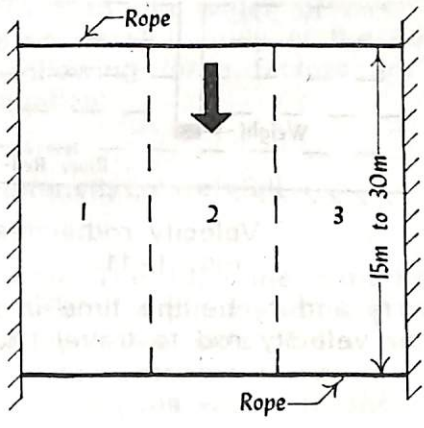
The formula was given by Bazin in 1897.

(b) By direct observation:

Following procedure is adopted to obtain the velocity of flow by the direct observation:

(i) The two lines, as shown in fig. 1–9, are marked across the river with the help of ropes. The distance between these *two* lines depends on the width of river. But it is usually kept as 15 m to 30 m.

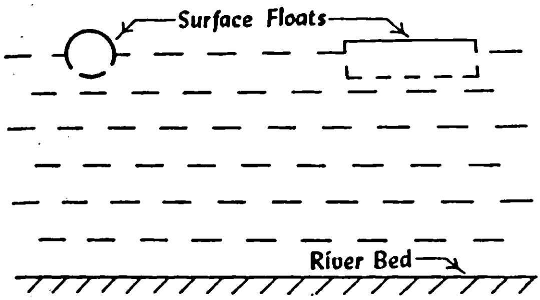
(ii) The width of river between these *two* lines is suitably divided, usually in *three* sections, as shown in fig. 1–9.



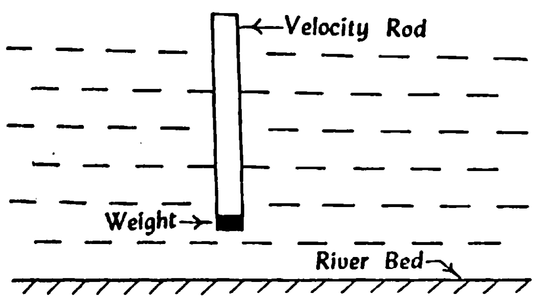
Measurement of velocity of flow by direct observation

FIG. 1–9

(iii) The time taken by a surface float or a velocity rod to travel from one line to the other is noted. The surface float is shown in fig. 1–10 and it is to be adopted for small rivers. The velocity rod is shown in fig. 1–11 and it is to be adopted for large rivers. The surface floats are made of light materials such as cork or drift wood and they are generally of diameter varying from 80 mm to 160 mm. The velocity rods are made of hollow metal tube or wood and they are generally of diameter varying from 30 mm to 50 mm. The velocity rods are provided with weight at their bottom so that they can float vertically with their top just above the water surface. They are made of adjustable lengths to suit the different depths of water.



Surface float
FIG. 1–10



Velocity rod
FIG. 1–11

(iv) Let t_1, t_2 and t_3 be the time in seconds taken by surface float or velocity rod to travel from one line to the other.

Then,

$$\text{Average time} = \frac{t_1 + t_2 + t_3}{3} \text{ seconds.}$$

(v) Velocity of flow in cm per second is then obtained as follows:

$$\text{Velocity} = \frac{\text{distance travelled in cm}}{\text{time in seconds}}$$

Following points should be noted:

(1) When surface floats are used, they give surface velocity and hence, to obtain mean velocity, the following correction is to be applied:

Mean velocity = e × surface velocity

where e = 0.8, if surface velocity is less than 90 cm/sec.

= 0.9, if surface velocity exceeds 90 cm/sec.

(2) The velocity rods give directly the mean velocity and hence, no correction is necessary, when they are used.

(3) The special instruments, known as the *velocity meters* may be used to obtain directly the velocity of flow. The meter is lowered from a boat and by applying formula for the meter, the mean velocity of flow can be worked out.

(2) Indirect method: Following are the *two* indirect ways of estimating the maximum flood discharge:

(i) Rational method

(ii) Use of empirical formulae.

(i) *Rational method:* The upstream area from the bridge site which contributes to the water of river is known as its *catchment area.* A careful study of the catchment area is made and the following *three* factors are combined in the form of an equation:

(1) Catchment area

(2) Maximum intensity of rainfall

(3) Runoff coefficient.

(1) Catchment area: The ridge line is marked on the topo sheet and with the help of a planimeter, the catchment area of the river on the upstream side of the proposed bridge site is worked out. If the catchment area is large, it should be divided into small sections with reference to the rainfall and topography. Then, the discharge or runoff from each section should be worked out separately and added together to get the total discharge.

(2) Maximum intensity of rainfall: The rainfall is measured by the standard instruments which are known as the rain gauges. They may be non–automatic or automatic. The Simon's non–automatic rain gauge is commonly used in India. The rain gauge stations should be evenly distributed over the area so as to obtain the representative figure of rainfall for the entire area. For hilly areas, they are situated nearer and for plain country, one station is provided for an area of about 130 km^2. The rain gauge stations should not be obstructed by roofs of buildings, large trees, etc.

The readings for record of daily rainfall are taken at an interval of 24 hours. The monthly rainfall and yearly rainfall can then be worked out from the data of daily rainfall. From the records of rainfall, the maximum intensity of rainfall of catchment area of the proposed bridge site is obtained.

(3) Runoff coefficient: The rainfall on an area is expressed as so many centimetres over the entire area for a certain fixed interval of time. But all the water coming down from the rainfall is not available for further use. Some quantity of it is lost in evaporation or percolation or transpiration. The *evaporation* is the loss of water from land and water surfaces back to the atmosphere due to action of heat of the sun. The *percolation* indicates the loss of water penetrated into the soil. The *transpiration* is the loss of water caused by the leaves of the growing vegetation. The net quantity of water which remains on surface after all the losses is termed as the surface runoff.

The term runoff coefficient is used to indicate the ratio of surface runoff from an area to the total rainfall on that area in a fixed interval of time. The value of runoff coefficient varies from 0.20 to 0.70 and it should be carefully decided as it depends on a combination of so many factors and its prediction becomes far from exact science. The factors which contribute to the flood flow are as follows:

(1) Area of catchment: The smaller the catchment area, the smaller will be the coefficient of runoff and vice versa.

(2) Characteristics of catchment: It is very essential to study in detail the characteristics of catchment area as they considerably affect the value of runoff coefficient. The matters to be studied are size, slope, vegetation, porosity, climate, etc.

(3) Condition of ground at the time of rainfall: If ground is dry at the time of rainfall, it will absorb more water and coefficient of runoff will be small. For ground wet at the time of rainfall, reverse will be the case.

(4) Intensity of rainfall: If it rains heavily in short duration of time, the soil does not get opportunity to absorb all the water. It thus increases the surface flow and consequently, the coefficient of runoff is also increased.

(5) Interval between successive showers: The smaller the interval between successive rainfall showers, the greater will be the coefficient of runoff and vice versa.

(6) Season of rainfall: The rainfall during hot season gives less surface flow than that during cold season.

(7) Yearly rainfall: The greater the annual rainfall, the greater is the runoff coefficient and vice versa.

Let A = Area of catchment in hectares

I = Maximum intensity of rainfall in cm per hour for duration of time of concentration

P = Coefficient of surface runoff

Q = Maximum flood discharge in m^3 per second.

Then, the general equation becomes as follows:

$$Q = K\,A\,I\,P$$

where K = Constant which permits the expression of *three* factors in convenient units.

In this case, with units as mentioned above,

$$Q = 10000\,A \times \frac{1}{100} \times \frac{1}{3600} \times I \times P$$

$$= \frac{AIP}{36}.$$

Hence, K is equal to $\frac{1}{36}$.

Problem 1-1.

From the following data, calculate lineal waterway required for a bridge to be constructed across the river:

Catchment area	:	*600 hectares*
Maximum intensity of rainfall	:	*1 cm per hour*
Runoff coefficient	:	*60 per cent*
Permissible velocity	:	*120 cm per second*
Average depth of flow	:	*180 cm.*

Solution:

$$Q = \frac{AIP}{36}$$

In the given problem,

A = Area of catchment in hectares

= 600 hectares

I = Maximum intensity of rainfall in cm per hour

= 1 cm

P = Runoff coefficient

= 0.60.

Hence,

Q = Maximum flood discharge in m^3 per second

$$= \frac{600 \times 1 \times 0.60}{36}$$

= 10.00 m^3 per second.

$$\text{Waterway} = \frac{Q}{V} = \frac{10.00}{1.20}$$

= 8.33 m^2.

$$\text{Lineal waterway} = \frac{8.33}{\text{av. depth of flow}} = \frac{8.33}{1.80} = 4.63 \text{ m.}$$

Two spans each of 3 m will be sufficient. ...... *Ans.*

The most important rational method which is now universally adopted is the unit hydrograph method. It was presented as early as 1932 by Le Roy K. Sherman. This method is laborious and time–consuming because it requires the collection of extensive data and if the discharge data for the site are not available, the discharge observations will have to be made for two or three seasons. This method therefore requires actual observations of the discharge at the site for some period and also rainfall data spread over some years.

A unit hydrograph is defined as a hydrograph representing a unit depth, say 1 cm, of runoff from a rainfall of some unit duration and distributed over specific area.

The ordinates of the unit hydrograph, within close approximate limits, are proportional to the volume of surface runoff resulting from the rainfall of unit duration, irrespective of the amount of such rainfall. Following are the *two* limitations of this method:

(1) *Discharge data:* It can be applied only for situations where part discharge data at the site and sufficient rainfall data are available. Alternatively, sufficient time should be available for making discharge observations at the site at least for one representative season.

(2) *Size of catchment area:* The storms beyond a certain area will not cover the whole catchment area during unit duration. It is therefore considered safe to apply this method directly for catchment areas of size not exceeding 25000 km^2.

(ii) *Use of empirical formulae:* For finding out the maximum flood discharge, certain empirical formulae have been developed by many eminent metereologists and engineers by past observations in similar areas. These formulae directly give the maximum flood discharge of a river. Following are the commonly used *three* empirical formulae in our country:

(1) Dickens formula:

$$Q = CA^{3/4}$$

(2) Ryves formula:

$$Q = CA^{2/3}$$

(3) Inglis formula:

$$Q = \frac{123\,A}{\sqrt{A + 10.36}}$$

where Q = Maximum flood discharge in m^3 per second.

A = Area of catchment in km^2

C = Constant depending on the nature of the catchment and its location.

Following points should be noted in connection with the use of empirical formulae:

(1) The values of constant C for Dicken's and Ryve's formulae are different. It depends on the characteristics of catchment. It is less for flat catchment and more for hilly catchment.

(2) Dickens formula is originally devised for the conditions in Central India. This formula was published as a professional paper in Indian Engineering Journal, Vol. II, 1965. Colonel Dickens selected the catchments of different sizes and made his observations on data available from the

rivers in Central India. He also found that his formula was applicable to areas having an annual mean rainfall of 600 mm to 1250 mm in North India. The value of constant is more for rivers with residual soil formed by the decomposition of the basalts and it is less for rivers with alluvial drift soils. The value of constant *C* varies from 11 to 22.

(3) Ryves formula is originally devised for conditions in the old Madras Presidency where soil is of residual type formed from metamorphic rocks. Ryves was an engineer working in Madras and he developed his formula by collecting data of rivers in Southern India. The value of constant increases as the distance of river from the coast increases. Its value is taken as 6.5 for flat tracks near the coast, 8.5 for areas between 25 km and 50 km of the coast and 10 for limited areas near the hills.

(4) Inglis formula is originally devised for the old Bombay Presidency. Colonel Inglis was working in the then Bombay Presidency and he published Technical paper No. 30, Bombay PWD, 1930 on the subject, 'A Critical Study of Run–off and Floods of Catchments in Bombay Presidency'. He had collected the statistical data of 65 sites in Bombay State and by plotting the graph of the discharge for corresponding areas, he had evolved his formula. His original formula was later on modified slightly, as mentioned above, for the fan shaped catchments.

(5) The Beale's and Whiting's curves can also be used to find out maximum flood discharge. The envelope curve for the design flood discharge for Indian rivers has also been evolved by Kanwar Sain and Karpov of the Central Water and Power Commission. They have drawn *two* separate curves—one for North Indian rivers and the other for those in South India. These curves directly give discharge against area of catchment.

It should however be remembered that these empirical formulas are over simplified and they give reliable results only if correct value of *C* is adopted. The reliable value of constant *C* can only be obtained by a careful study of catchment area with respect to flood occurrence for a long time and it is still doubtful whether such a value of constant can be applied with success to entirely different region. Hence, the reliability of empirical formulas for estimating the maximum flood discharge is extremely limited in practical field and the limitations of this method can be summarized as follows:

(1) It is not possible to apply this method universally.

(2) It is very difficult to fix the constant of formulas and there is no exact procedure or theory for accurately predicting the value of constant.

(3) The empirical formulas do not take into consideration the frequency of flood.

Number of spans:

The number of spans for a bridge should be carefully decided by considering all the aspects of bridge such as cost of construction, nature of flow, importance of bridge, materials available, etc. Following important points are to be remembered while deciding the number of spans for a bridge:

(1) *Alternative proposals:* It is desirable to prepare 3 or 4 alternative proposals of number of spans for a bridge and then, the one which is most economical, convenient and suitable, should be recommended.

(2) *Foundations for piers:* The foundations available for piers also play an important role in determining the number of spans for a bridge. The piers should rest on firm and stable soil.

(3) *Odd number of spans:* It is desirable to adopt odd number of spans for a bridge. The velocity of flow is the highest at centre of length of a bridge. An odd number of spans will provide an opening in the centre of length of a bridge. The pier in the middle of stream is likely to be hit directly by the swiftest part of the flow and it is also subjected to very deep scour.

(4) *Span:* It is desirable to have spans as large as possible. In other words, the number of spans should be restricted to as few as possible especially in mountainous regions where torrential velocities prevail. It will allow smooth passage of flood water. But there is considerable rise in the cost of a bridge beyond a certain span. On the other hand, the small spans will require more piers and hence, the waterway under the bridge will be seriously obstructed. A compromise between these *two* conflicting situations should be properly made.

Preliminary and final project drawings:

Following preliminary drawings will have to be prepared and studied in the initial stages of the bridge site investigation:

(1) *Catchment area map:* This map is prepared from the topographical maps of Survey of India which is drawn to a scale of 1/50000 and it indicates the catchment area likely to contribute water at the proposed bridge site. It will assist in determining the design discharge by using some proper flood formula.

(2) *Contour plan:* It should cover a sufficient distance on either side of the bridge site so as to give a clear idea of features affecting location and design of bridge. According to the Indian Roads Congress, the distances to be covered by the plan on either side of bridge site for catchment areas of 3 km², 15 km² and over 15 km² should be respectively 100 m, 300 m and 1500 m.

(3) *Cross–sections:* The informations such as low water level, ordinary flood level, highest flood level, river bed line, nature of subsoil, etc. should be shown on various cross–sections taken at suitable distances on upstream and down–stream sides of the proposed bridge site and drawn to suitable horizontal scale (not less than 1/1000) and vertical scale (not less than 1/100). For important bridges, the cross–sections should contain the following particulars:

(i) bed line upto the top of banks and the ground line to a sufficient distance beyond the edges of river;
(ii) depth of scour below the highest flood level;
(iii) maximum discharge and average velocity of flow at the bridge site;
(iv) name of road with its chainage;
(v) name of the stream or river;
(vi) positions of low water level, ordinary flood level and the highest flood level; etc.

(4) *Index map:* It is drawn to a convenient scale. In case of small rivers, the scale is 1:50000 while for large ones, it is 1:250000. It exhibits the alternative sites investigated, existing routes of communications, general topographical features of the area, important nearby towns and villages, geographical location of the bridge, etc.

(5) *Longitudinal section:* It should be drawn roughly with reference to the centre–line of the deep water channel of the stream or river and should indicate low water level, ordinary flood level, highest flood level and bed level of points at suitably spaced intervals. It should be plotted with the horizontal scale of not less than 1/2500 and with the vertical scale of not less than 1/1000.

(6) *Soil profile:* The borings should be taken at the approximate locations of abutments and piers along the bridge so as to get an idea of subsoil conditions indicating the location of water table and its depth, thickness and composition of each soil strata, etc. It should also indicate the levels of bed, bank and depth of soil suitable for the resting of the foundations. For culverts and minor bridges, a simple soil investigation will be sufficient. The normal practice adopted for the major bridges is that the investigations are conducted upto a depth equal to 1.5 times the proposed width of foundation below the proposed bottom of foundation.

The detailed final project drawings of the bridge showing the construction details should be ready before the construction work of the bridge is started. In addition to the structural and working drawings of the project, it is necessary to prepare a detailed site plan of the project containing the following informations:

(1) catchment area;
(2) direction of the flow of water;
(3) formation level of the roadway;
(4) ground levels along both the banks of the river for a reasonable distance, say about 150 m or so;
(5) highest flood level, ordinary flood level and low water level;
(6) maximum clear lineal waterway required;
(7) maximum discharge in the river;
(8) maximum expected or observed depth of scour;
(9) maximum velocity of flow of water;
(10) name of the river or stream;
(11) names of the towns at either end of the bridge;
(12) north line;
(13) position of bench mark used as datum;
(14) radius of curvature of the approach road;
(15) results of trial pits or bore holes along bridge site indicating various strata of soil;
(16) topographical features of the roundabout area;
(17) width of approaches;
(18) width of bridge; etc.

Choice of bridge type:

There is no hard and fast rule for selecting a particular type of bridge in all cases. As a matter of fact, the various possible alternatives can be worked out and the ultimate choice should be made for that type of bridge which will give the maximum benefits and would involve favourable conditions for its construction. In general, the bridge should be aesthetically pleasing in appearance, strong enough to carry the traffic and other incidental loads, economical, etc. Some of the aspects which influence the choice to be made between different types of bridges are as follows:

(1) *Approaches:* The formation level and length of approaches at bridge site will also have considerable influence on the choice of a particular type of bridge.

(2) *Availability of funds:* If the fund available is not sufficient to put up a high level bridge, the small submersible bridge or causeway may be recommended instead of totally abandoning the project for lack of money.

(3) *Climatic conditions:* If the environmental conditions are unsuitable or unfavourable, certain types of the bridges cannot be constructed. For instance, if the climatic conditions at bridge site are likely to accelerate the process of corrosion, the steel trusses cannot be adopted.

(4) *Economy in construction:* If the river is wide, the economy in construction can be achieved by putting up a road–cum–rail bridge in two tiers instead of two separate bridges, namely, highway bridge and railway bridge. It will result in the economy in construction.

(5) *Foundations:* The soil conditions at bridge site may bring down the possible alternatives and under such circumstances, the choice of a particular type of bridge is to be made from such limited alternatives only.

(6) *Navigational requirements:* If it is desired to have more vertical clearance for satisfying the navigational requirements of the community or locality, certain types of bridges such as arch bridges, suspension bridges, etc. will only have to be selected.

(7) *Specialized firm:* If the tender for long bridge is invited on competitive basis with freedom to submit the alternative designs by the tenderers, it is likely that the type of bridge to be selected finally will be influenced by the specialization achieved by a particular firm for a certain type of bridge. Each specialized firm will try to convince about the adaptibility of its design for a particular bridge site.

(8) *Type of traffic:* The choice of bridge type will also be governed by the nature of traffic. For instance, the steel trusses are preferable to the suspension bridges for railway traffic. Normally, the bridge forms part of an overall

project like the construction of a new road or a new railway line. Hence, the traffic forecast is made for the project as such and it will help in determining the size of bridge i.e. the number of lanes or tracks to be provided. It should be seen that the type of bridge is such that the volume of traffic that will develop for a future period of say about 30 years is accommodated without any additional work or reconstruction of the bridge.

QUESTIONS

1. What is a bridge? Mention the factors which are responsible for putting the subject of bridge engineering on scientific footing.
2. Briefly outline the development of bridges.
3. Mention the ways in which bridges are classified.
4. What is meant by the identification of bridges?
5. What preliminary data should be collected and analysed by engineer–in–charge of the investigation of a bridge site?
6. What are the factors to be considered while selecting the site for a proposed bridge?
7. Mention the permissible velocities for different types of beds of river.
8. Describe in detail the various stages of investigation for important bridges.
9. Describe the aspects to be studied with respect to bridge alignment.
10. Explain briefly how waterway of a bridge is determined.
11. How is maximum flood discharge of a river determined by direct method?
12. What are the traffic requirements of highway bridges?
13. Write short notes on:
    (1) Changing scenario in design and construction of bridges
    (2) Importance of bridges
    (3) Skew bridges
    (4) Chezy's formula
    (5) Rain gauges
    (6) Unit hydrograph.

14. How is maximum flood discharge of a river determined from the study of catchment area?

15. Mention the formulae which are commonly used to work out the maximum flood discharge.

16. What are the factors which affect the value of runoff coefficient?

17. What are the points to be remembered while deciding the number of spans for a bridge?

18. Mention the preliminary drawings which are to be prepared and studied in the initial stages of bridge site investigation.

19. Enumerate the informations to be accommodated in the detailed site plan of the bridge project.

20. What are the aspects which influence the choice of type of bridge?

21. A new culvert is constructed between the 4th and 5th culverts in tenth kilometre i.e. between kilometre stones 9 and 10. State the correct designation from the following alternatives:

$\frac{10}{4}$, $\frac{10}{4-1}$, $\frac{10}{5-1}$, $\frac{10}{1-4}$. [Ans. $\frac{10}{4-1}$]

22. From the list given below, find out the identification which suggests a new culvert constructed between 2nd and 3rd culverts on a highway between kilometre stones 80 and 81:

(1) $\frac{81}{2-1}$ (2) $\frac{80}{1-2}$ (3) $\frac{80}{3-1}$ (4) $\frac{80}{1-3}$

[Ans. $\frac{81}{2-1}$]

23. Differentiate between the following:

(1) Minor bridges and major bridges
(2) Natural waterway and lineal waterway
(3) Sounding poles, lead lines and sounding machines
(4) Surface float and velocity rod
(5) Total rainfall and surface runoff
(6) Evaporation, percolation and transpiration
(7) Preliminary and final project drawings.

24. Give reasons for the following:

(1) The development of bridge construction is closely associated with the history of human civilization.

(2) The subject of bridge engineering is given special attention during the course of military training.

(3) The skew or slanting bridges are usually avoided.

(4) It is very important to check that the velocity of flow at bridge site is proper.

(5) All the water coming down from the rainfall is not available for further use.

(6) It is desirable to adopt odd number of spans for a bridge.

(7) There is no hard and fast rule for selecting a particular type of bridge in all cases.

(8) The Indian Roads Congress have prepared the code for identifying the culverts and bridges.

(9) The bridges across rivers and streams are the most vulnerable.

(10) The approaches should avoid the cutting across the built–up area or religious structures.

(11) It is desirable to have normal crossing.

(12) In case of very major bridges, it is necessary to carry out the model studies.

(13) The construction of bridge calls for the utmost economy.

(14) In technical feasibility stage, the entire length of the river within the area to be interconnected has to be studied.

(15) The stability of the bridge structure at the nodal points is insured.

(16) The lead line should be soaked in water for about an hour before it is used for taking soundings.

(17) The electronic echo sounders directly measure the depth of water.

(18) The value of runoff coefficient should be carefully decided.

(19) The unit hydrograph method is laborious and time–consuming.

Chapter 2

FOUNDATIONS

General:

The foundations are required to distribute equally and uniformly the total load of the bridge on the soil. The design of bridge foundations in general should conform to the standard specifications and code of practice for bridges prescribed in IRC bridge code section – 7 (IRC:78–1983). In this chapter, brief descriptions of the foundations for bridges in particular will be given.

The topic of foundations is very extensive and hence, for detailed description, the reader may refer to the author's book on 'Building Construction'.

Essential requirements of a good foundation:

Following are the *three* basic requirements to be fulfilled by a foundation to be satisfactory:

(1) Location

(2) Stability

(3) Settlement.

(1) *Location:* The foundation structure should be so located that it is able to resist any unexpected future influence which may adversely affect its performance. This aspect requires careful engineering judgement.

(2) *Stability:* The foundation structure should be stable or safe against any possible failure.

(3) *Settlement:* The foundation structure should not settle or deflect to such an extent so as to impair its usefulness. It is, however, difficult to define the objectionable amount of settlement or deflection. It should also be seen that the differential settlement is so limited as not to cause any damage to the structure.

The term differential settlement is used to indicate the non–uniform settlements of different points of the same foundation or of two independent foundations. It is mainly due to prevailing foundation bed conditions at site.

The above *three* requirements are independent of each other and for the foundation structure to be satisfactory, all the *three* conditions should be simultaneously satisfied.

General principles of design of bridge foundations:

Following *three* factors influence the design of bridge foundations:

(1) Bearing capacity of soil
(2) Frictional resistance
(3) Scour.

(1) *Bearing capacity of soil:* The bridge foundations should be taken to such a depth that the soil at that depth has sufficient safe bearing capacity to withstand the load coming upon it without any settlement. It is therefore necessary to decide carefully the soil strata with requisite safe bearing capacity. If W is the total load on bridge foundation and A is the area of bridge foundation, the ratio $\frac{W}{A}$ should be less than or equal to the safe bearing capacity of soil.

(2) *Frictional resistance:* Some foundations resist the load coming upon them by the friction offered by the surrounding soil. In such cases, the bridge foundations should be taken upto suitable depth so that enough frictional resistance is developed to resist the load coming on the bridge foundations.

(3) *Scour:* The term *scour* is used to indicate the increase in depth in vertical direction of the bed of river. Such increase in depth mainly occurs due to the currents of flowing water, bed material, alignment of river, flood discharge, bed slope, direction of flow, shape of pier, etc. The scouring action of the current is not uniform all along the bed width. It is not so even in straight reaches. There is deeper scour than normal at the piers or other obstructions and also at bends. Hence, it is necessary to determine the maximum scour depth and the bridge foundations should be taken beyond this maximum depth of scour. The term scour should not be confused with erosion which indicates the horizontal widening of river.

The empirical formulae are used to work out the depth of scour. Following are *two* commonly used empirical formulae:

(i) *For normal sites having straight currents and slightly contracted waterway:*

$$s = \frac{1.3\,dv_1}{v} \text{ or } \frac{2.1\,mv_1}{v}, \text{ whichever is greater}$$

where s = maximum depth of scour below H.F.L.
d = maximum depth of bed of river below H.F.L.

v_1 = average velocity of flow under the bridge
v = average velocity of flow in the river
m = hydraulic mean depth.

(ii) *For bad sites having diagonal currents and appreciably contracted waterway:*

$$s = \frac{1.5 d v_1}{v} \text{ or } \frac{2.9 m v_1}{v}, \text{ whichever is greater}$$

where the meanings of s, d, v_1, v and m are same as above.

It should, however, be noted that precautions should be taken to minimize the effect of scour. Following are such precautions:

(i) If the river bed consists of sand, it will be desirable to provide sheet piles on the upstream and downstream sides of the bridge to reduce the chances of scouring.

(ii) The bed of river at bridge site should be covered with particles of suitable weight and shape.

(iii) The flow of water at bridge site should be a stream line flow and not a turbulent flow.

(iv) The piers should be so shaped that the formation of eddies and currents is avoided.

(v) The river bed on upstream side, portion below the bridge and downstream side should be suitably pitched with heavy and long stones.

(vi) The velocity of flow at bridge site should be non-scouring.

(vii) To prevent scouring, the piles can be driven in the river bed.

In addition to the empirical formulae mentioned above, there are various methods for the determination of maximum scour depth. But the method which has gained wide popularity in India is based on the following Lacey's regime equation:

$$s = 0.473 \left(\frac{Q}{f}\right)^{1/3}$$

where s = Normal depth of scour in m below H.F.L.
Q = Discharge in m^3/sec.
f = Lacey's silt factor.

The value of Lacey's silt factor is approximately calculated from the expression,

$$f = 1.76 \sqrt{m}$$

where m = Mean diameter of the bed material in mm.

Table 2–1 gives the values of *f* which are commonly adopted in practice.

TABLE 2–1
VALUES OF LACEY'S FACTOR

No.	Type of bed material	Mean dia. of particle in mm	Value of *f*
1.	Very fine silt	0.052	0.40
2.	Fine silt (Godavary River Western India)	0.081	0.50
3.	Fine silt	0.120	0.60
4.	Fine silt (Kistna Western Delta Type)	0.158	0.70
5.	Medium silt	0.233	0.85
6.	Standard silt	0.323	1.00
7.	Medium sand	0.505	1.25
8.	Coarse sand	0.725	1.50
9.	Fine bajri (pebbles)	0.988	1.75
10.	Medium bajri (pebbles)	1.290	2.00
11.	Coarse bajri (pebbles)	2.422	2.75
12.	Medium gravel	7.280	4.75
13.	Small boulders	50.10	12.00
14.	Medium boulders	72.50	15.00
15.	Large boulders	188.80	24.00

For the natural streams, the maximum scour depth is not uniform and it is obtained by the following expression:

$$s_{max} = s \times R$$

where s_{max} = Maximum scour depth
s = Normal scour depth
R = Constant.

Table 2–2 gives the values of *R* under different conditions of flow.

TABLE 2–2
CONSTANTS FOR MAXIMUM DEPTH OF SCOUR

No.	Condition of flow	Value of *R*
1.	For straight reach	1.27
2.	At moderate bend	1.50
3.	At sharp or severe bend	1.75
4.	At right angled bend	2.00
5.	At upstream noses of guide banks	2.75
6.	At the noses of bridge piers	2.00

It has also been observed that the maximum scour in case of abutment occurs at the upstream corner, whereas in case of piers, it occurs at the downstream nose end.

When the linear waterway is less than the regime depth, the value of normal scour depth with contracted waterway is given by the following expression:

$$s_1 = s \left(\frac{W}{L}\right)^{0.61}$$

where s_1 = Normal scour depth with contracted waterway

W = Lacey's regime width of river

L = Width of waterway below bridge.

It may be noted that Lacey's regime surface width of river in m is given by the expression,

$$W = 4.8 \sqrt{Q}$$

where Q = Flood discharge in m^3/sec.

Problem 2-1.

The flood discharge under a bridge is 750 m^3/sec. The bridge site is at right angled bend. Assuming Lacey's silt factor for river bed as 0.85, calculate the maximum scour depth.

Solution:

$$s_{max} = s \times R$$

$$= 0.473 \left(\frac{Q}{f}\right)^{1/3} \times R.$$

In the given problem,

Q = 750 m^3/sec

f = 0.85

R = 2.00 (from table 2-2).

Substituting,

$$s_{max} = 0.473 \left(\frac{750}{0.85}\right)^{1/3} \times 2.00 = 9.07 \text{ m.} \quad \ldots\ldots \text{ Ans.}$$

Problem 2-2.

A bridge is proposed to be constructed across an alluvial stream carrying a discharge of 250 m^3/sec. Assuming the value of silt factor f = 1.00, determine the maximum scour depth when the bridge consists of 4 spans, each of 20 m.

Solution:

Lacey's regime surface width of river is given by the expression,

$$W = 4.8\sqrt{Q}\,.$$

Substituting $Q = 250 \text{ m}^3/\text{sec}$

$$W = 4.8\sqrt{250}$$

$$= 75.89 \text{ m.}$$

The bridge consists of 4 spans of 20 m each.

$\therefore \quad L = 4 \times 20 = 80$ m.

As $\quad L > W$

Normal scour depth = Regime depth

$$\therefore \quad s = 0.473\left(\frac{Q}{f}\right)^{1/3} = \left(\frac{250}{1}\right)^{1/3} = 2.98 \text{ m, say 3 m.}$$

As the bridge has got four spans, it will have three piers and two abutments. The maximum scour depth will occur at the noses of piers and it will be worked out by the following equation:

$s_{max} = s \times R$ where $R = 2.00$

$\therefore \quad s_{max} = 3 \times 2 = 6$ m. .... *Ans.*

Problem 2-3.

If the bridge in the above problem consists of 3 spans each of 20 m, what will be the maximum depth of scour?

Solution:

In this case,

$W = 75.89$ m as above.

The bridge consists of 3 spans of 20 m each.

$\therefore \quad L = 3 \times 20 = 60$ m.

As $L < W$, the normal scour depth with contracted waterway will be obtained by the expression,

$$s_1 = s\left(\frac{W}{L}\right)^{0.61}$$

$$= 3\left(\frac{75.89}{60}\right)^{0.61}$$

$$= 3.46 \text{ m.}$$

As the bridge has got three spans, it will have two piers and two abutments. The maximum scour depth in this case also will occur at the noses of piers and it will be worked out by the following equation:

$$s_{max} = s_1 \times R$$

where $R = 2.00$

$$= 3.46 \times 2.00$$

$$= 6.92 \text{ m}$$ .... *Ans.*

Subsoil exploration:

The determination of the correct subsoil exploration at the proposed bridge site is necessary for the following reasons:

(1) It assists the designer to make an economic design of the foundations for the bridge piers and abutments consistent with the existing subsoil conditions.

(2) It avoids the defects in the bridge structures which would have occurred because of lack of the subsoil information.

(3) It gives the correct idea of the nature of strata underlying at various points along the bridge site.

(4) The subsoil information assists the competing contractors to quote their rates correctly.

The data to be collected during subsoil exploration include depth of rock bed, engineering qualities of soils and rocks, nature and depth of soil deposits, water table location, etc. At the preliminary stage, it will be enough to get a general idea of the nature of soil strata. But when the bridge site is finally selected, the detailed subsoil information should be gathered by employing any suitable method of subsoil exploration.

Following are the methods commonly adopted to obtain soil samples for getting the information of the subsoil conditions:

(1) *Test pits:* A square pit, known as a trial pit or a test pit, with side as about 1.50 m, is excavated upto a depth at which sufficient hard soil is available. The various strata of the soil can be inspected, studied and classified accordingly. This method is useful when the hard soil is available with a maximum depth of 1.50 m.

(2) *Probing:* It consists of driving a hollow tube or a steel rod or an iron rod into the ground. The material caught or stuck up is examined. This method is useful to examine the ground for a maximum depth of 3 m.

(3) *Auger boring:* An auger may be of post hole type or screw type or shell type. They all work in the same way. The samples are taken out in the augers and they are examined for identification and grain size analysis. When the auger is to be driven in loose sand, it becomes essential to prevent the collapse of the loose material, when the auger is being withdrawn. A casing is a thin metal tube having a slightly bigger diameter than the auger and it is driven ahead of the auger. The lengthening of the casing can be done by connecting one pipe to the other. With the help of this method, it is possible to inspect the ground for a depth of 6 m to 8 m and in case of loose sand, the auger may be useful even upto a depth of 15 m or so.

(4) *Wash boring:* The term wash boring is used to denote a method in which a casing is driven into the ground and the material inside the casing is washed out and brought to the surface for inspection. The results obtained by this process are reliable when depths are about 30 m to 45 m.

At intervals, usually 1.50 m to 2 m or whenever the stratum changes, the washing is stopped, the tube lifted up and a tube sampler is attached to the drill rod or inner tube is driven into the soil below to collect the undisturbed samples. The wash boring can then be continued further after lowering the tube again.

(5) *Test piles:* Sometimes, the test piles are driven into the ground to obtain the information of the solid strata. With the help of this process, it is not possible to know definitely the kinds of strata through which test piles pass, as the material is not available for inspection. But the factors such as resistance of soil to driving of piles, load bearing data and any other available local information serve as useful guides.

(6) *Deep boring:* For important works, the deep boring is done with the help of either percussion boring machine or core drilling machine. The information obtained is plotted in the form of a core chart. In percussion boring, the soil is broken up by repeated blows by a chisel or bit dropped from above. The casing pipe may be used for extending the bore. The water may be added to the hole at the time of chiselling for easing the material, if it is hard. The samples collected in percussion boring are normally disturbed and as the material gets broken up and pulverised, this method is not suitable for careful investigation.

If there is rocky stratum below, the core drilling is adopted. The water is circulated down the hollow rod to which the drill is attached. The core drill is designed in such a way that a continuous recovery of the core can be achieved and these cores are retained as samples.

(7) *Geophysical method:* In favourable circumstances, the geophysical method is adopted to know the nature of soil strata. The geophysical method may either be seismic or electrical.

Testing of soil samples:

Table 2–3 shows the various laboratory tests which are usually carried out on the soil samples for determining the properties mentioned against each test.

The tests 4, 5 and 7 provide general characteristics of the soil and they give an idea of excavation problems. The test no. 1 also helps in determining the silt factor necessary for working out the scour depth.

The test nos. 3, 6 and 7 with SPT (standard penetration test) values, help in determining the frictional properties, sinking difficulties and the bearing capacity of the soil.

The test nos. 2 and 8 help in the determination of the likely settlement. The test no. 1 gives an idea of the chemical property of the soil and suggest the presence of any harmful gases likely to be encountered during excavation. It will also assist in predicting whether the soil is likely to affect adversely the foundation material of steel or concrete.

TABLE 2–3
LABORATORY TESTS FOR SOIL SAMPLES

No.	Test	Properties of soil to be determined
1.	Chemical analysis	Soluble salts in rock sample for erodibility
2.	Consolidation	Compressibility
3.	Direct shear and triaxial	Shear strength for non–cohesive soil or any soil
4.	Liquid limit and plastic limit	Consistency
5.	Mechanical and wet analysis	Grain size distribution
6.	Spcific gravity and dry density	Void ratio and unit weight
7.	Unconfined compression	Shear strength of cohesive soil
8.	Vane test	Shear strength and sensitivity of clay

Following site tests of the soil samples can also be carried out for getting first hand information about the nature of soil:

(1) *Plate bearing test:* This test is carried out to determine the bearing capacity of the soil for shallow foundations.

(2) *Standard penetration test (SPT):* This test is usually done simultaneously with the collection of the sample by using the same sampling tube.

(3) *Vane shear test:* These tests have to be carried out in clayey soil for determining in–situ value of shear strength especially for sensitive clays which lose part of their strength even when disturbed slightly.

Types of foundations:

The bridge foundations can be divided into the following *three* categories:

(1) Spread foundations
(2) Pile foundations
(3) Caissons.

Each of the above type of foundation will now be briefly described.

(1) *Spread foundations:* The spread foundations are sometimes referred to as the *open foundations* as the construction work is to be carried out in open excavation. In case of spread foundations, the concrete footing is provided with suitable projections. As the construction work is to be carried out in open, the spread foundations are adopted where depth of water is not more and good soil is available at shallow depth.

Following *two* precautions should be taken in the design of spread foundations:

(i) It should be seen that no tension develops between the foundation bed and soil. For this purpose, it should be verified that the resultant force on the footing passes through the middle–third portion of the base.

(ii) The projections of concrete footing will be functioning as cantilevers and they will be subjected to uniform or non–uniform resistance from soil. In cases where reinforcement is not used, the depth of these projections should be such that bending moment and shear force due to cantilever action are safely resisted by them.

In actual practice, the different sections of the concrete footing are assumed by reference to similar bridges. The effects of various forces on them is then calculated. The most suitable section is then adopted.

(2) *Pile foundations:* The term *pile foundation* is used to describe a construction for the foundation of bridge piers which in turn is supported on the piles. The piles may be placed separately or they may be placed in the form of a cluster throughout the length of the pier. The pile foundations are adopted when the loose soil extends to a great depth. The load of the structure is transmitted by the piles to hard stratum below or it is resisted by the friction developed on the sides of piles. The piles are generally driven vertically or in near vertical position.

The materials commonly used to construct the bridge piers are cast-iron, cement concrete and steel.

The cement concrete possesses excellent compressive strength. With the advent of reinforced cement concrete, the R.C.C. piles are becoming more popular and they are fast replacing piles of other materials. The R.C.C. piles are divided into *two* groups:

(i) Cast-in-situ concrete piles

(ii) Precast concrete piles

(i) *Cast-in-situ concrete piles:* In case of cast-in-situ concrete piles, a bore is dug into the ground by inserting a casing. The bore is then filled with cement concrete after placing reinforcement, if any. The casing may be kept in position or it may be withdrawn. The former piles are known as the *cased cast-in-situ concrete piles* and the latter piles are known as the *uncased cast-in-situ concrete piles*.

(ii) *Precast concrete piles:* The precast concrete piles are manufactured in factory and they are then driven into the ground. A bore is dug into the ground by inserting steel shell. If shell is left in place, it is called a *shell pile*. If shell is removed, it is known as *shell less pile*. The precast concrete piles may be tapered or parallel-sided. They may be square, octagonal or round in shape. The square and octagonal piles are cast in horizontal forms and the round piles are cast in vertical forms. Generally square and circular section piles are preferred to other shapes.

Design steps for precast R.C.C. piles:

(1) Collect the required data like load, width and length of pier, size and spacing of piles, materials, etc.

(2) Depending on load and spacing, carry out the arrangements of piles and pile cap.

(3) Design pile reinforcements like longitudinal reinforcement, lateral reinforcement in body of pile, near pile head and near pile ends by assuming suitable data and by applying different equations as per IS: 456–1978.

(4) Finally design pile cap by computing maximum bending moment and reinforcement required.

(3) *Caissons:* The word *caisson* is derived from the French word *caisse* meaning a box. In Civil Engineering, a caisson is defined as structure which is sunk through ground or water to exclude water and semi–fluid material during the process of excavation of foundations and which subsequently becomes an integral part of the substructure. Fig. 2–1 shows the chart of classification of caissons.

Caissons

- Box caissons (open at top and closed at bottom)
- Wells (open at top and bottom)
  - Single
  - Multiple or Monoliths
  - Cylinders
- Pneumatic caissons (closed at top and open at bottom)

Chart showing classification of caissons

FIG. 2–1

(i) *Box caissons:* A box caisson is open at top and closed at bottom. The box caissons may be built of reinforced concrete, steel or timber. The box caissons are suitable when the velocity of flow of water is slow and the depth of water is about 6 m to 8 m.

(ii) *Wells:* A well is a caisson which is open at top as well as at bottom. It is provided with a cutting edge at the bottom so as to facilitate sinking. The shape of a well is generally decided by the requirements of the superstructure and it may be rectangular, circular or of any other shape.

When few intermediate piers are to be constructed, the dimensions of a single well become excessive due to heavy loads. In such cases, instead of a single well, a number of wells is provided. The pockets formed are used as dredging wells and the size and layout of these dredging units mainly depend on the nature of soil through which the well has to pass. If the number of wells is two, it is known as *twin well* and two wells may be combined to form an elliptical well in plan. If the number of wells is very large, a *monolith* is formed.

The well when to be sunk too deep becomes slender and it requires bigger dimensions. It then becomes excessively heavy in weight. In such cases, the metal wells are used instead of masonry or R.C.C. wells. Such a metal well of circular cross–section is known as a *cylinder* and it should be strong enough to resist the lateral pressure and side thrust.

The well foundation is favoured where large spans requiring deep foundations have to be provided. There is skill available throughout India for sinking wells and in many cases, it becomes the most economically viable alternative under the prevailing Indian conditions mainly for the following *two* reasons:

(1) The labour is cheap.

(2) The mechanical equipment is costly.

(iii) *Pneumatic caissons:* A pneumatic caisson is open at bottom and closed at top. The compressed air is used to remove water from the working chamber and the foundation work is carried out in dry conditions. The pneumatic caissons become useful when it is not possible to adopt wells. Such a condition may arise due to various factors such as soil to be tackled is of unusual properties or it contains boulders, buried timber, masonry, etc. The pneumatic caissons are adopted for depths of water ranging from 12 m to 35 m.

Cofferdams:

A *cofferdam* is defined as a temporary structure which is constructed so as to remove water from an area and make it possible to carry on the construction work under reasonably dry conditions.

Following are the requirements of a cofferdam:

(1) It should be reasonably watertight.

(2) The design and layout of a cofferdam should be such that the total cost of construction, maintenance and pumping is minimum.

(3) It should be designed for the maximum water–level and other destructive forces so as to make it stable against bursting, overturning and sliding.

(4) It is generally constructed at site of work.

(5) It should be so arranged that it facilitates easy dismantling and re–use of the materials.

The factors which would influence the selection of a particular type of cofferdam can be enumerated as follows:

(1) availability of the materials of construction of the cofferdam in the vicinity of site of work,
(2) availability of the transport facilities,
(3) depth of water at site of work,
(4) extent of area to be protected by the cofferdam,
(5) nature of bed on which the cofferdam is to rest,
(6) possibility of overtopping by floods, tides, etc.,
(7) possibility of scour due to the reduction of waterway caused by the construction of cofferdam,
(8) velocity of flowing water, etc.

The materials used in the construction of a cofferdam are earth, timber, steel and concrete. A wide variety of different types of cofferdams is available. The brief descriptions of the most common types of cofferdams are as follows:

(i) *Dikes:* A dike is an embankment of some material. The materials commonly employed for the construction of a dike ate earth, rock and sand–bags. The dikes are generally employed for a short duration, particularly to enable the construction of a more durable cofferdam behind them.

(ii) *Single wall cofferdams:* A single wall cofferdam is suitable when available working space is limited and the area to be enclosed is small. A single row of piles is used on either side of the cofferdam. A single wall cofferdam is suitable upto the maximum depth of water of 25 m.

(iii) *Double wall cofferdams:* When the area to be enclosed is large, it becomes essential to provide the double wall construction so as to give stability to the cofferdam.

(iv) *Cellular cofferdams:* The cellular cofferdam is made of steel sheet piles and it is proved successful in unwatering large areas. The cells are generally 10 m to 15 m in diameter and they are placed at a centre to centre distance of about 12 m to 18 m. The cellular cofferdams are suitable upto the maximum depths of water of 10 m to 15 m.

(v) *Rock-filled crib cofferdams:* A rock–filled crib cofferdam consists of timber cribs. A crib is a box or cell open at the bottom and it essentially consists of framework of horizontal timbers laid in alternate courses. The pockets thus formed are then filled with rock or gravel or earth to give stability to the crib against overturning and sliding. The rock–filled crib cofferdam is suitable when depth of water is about 10 m to 20 m.

(vi) *Concrete cofferdams:* The concrete cofferdams are actually small concrete dams and they have been used economically on many jobs of the concrete cofferdams. The framework usually consists of the precast R.C.C. piles and sheets. The precast R.C.C. sheet piles are provided with suitable edges. The main disadvantage of a concrete cofferdam is that it is costly. But when it is to be incorporated as part of a permanent structure, it proves to be economical.

(vii) *Suspended cofferdams:* Sometimes, a cofferdam is designed in such a way that a single unit of it is used several times. The cofferdam as such is lifted, floated and placed in another position as soon as its purpose is served. Such cofferdams are known as the suspended cofferdams or movable cofferdams.

QUESTIONS

1. What are the three basic requirements for a bridge foundation to be satisfactory?
2. Mention general principles of the design of bridge foundations.
3. Why subsoil exploration is necessary? Describe its various methods.
4. Explain in brief the various laboratory and site tests which are carried out on the soil samples.
5. Describe the construction of spread foundations for the bridges.
6. Discuss the utility of piles as the bridge foundations.
7. Write short notes on:
   (1) Depth of scour
   (2) R.C.C. piles
   (3) Wells
   (4) Dikes
   (5) Rock–filled crib cofferdams
   (6) Pneumatic caissons.
8. What is a caisson? Describe its various types.
9. Define a cofferdam and briefly describe its various types.
10. The flood discharge under a bridge is 370 m^3/sec. The bridge site is at severe bend. Assuming Lacey's silt factor for river bed as 0.60, calculate the maximum scour depth. (*Ans.* 7.05 m.)

11. A bridge site is proposed to be constructed across an alluvial stream carrying a discharge of 325 m^3/sec. Assuming the value of silt factor $f = 1.10$, determine the maximum scour depth when the bridge consists of 3 spans, each of 30 m. (*Ans.* 6.30 m.)

12. If the bridge in problem no. 11 consists of 2 spans each of 35 m, what will be the maximum depth of scour? (*Ans.* 7.16 m.)

13. What are the requirements of a cofferdam?

14. Enumerate the factors which would influence the selection of a particular type of cofferdam.

15. Differentiate between the following:
   (1) Test pits and test piles
   (2) Auger boring and wash boring
   (3) Spread foundations and pile foundations
   (4) Cast–in–situ and precast concrete piles
   (5) Twin well and monolith
   (6) Box caisson and pneumatic caisson
   (7) Cofferdam and caisson
   (8) Scour and erosion.

16. Give reasons for the following:
   (1) The bridge foundations should be taken beyond the maximum depth of scour.
   (2) The determination of the correct subsoil exploration at the proposed bridge site is necessary.
   (3) When the auger is to be driven in loose sand, a casing is driven ahead of the auger.
   (4) The spread foundations are adopted where depth of water is not more.
   (5) It should be verified that the resultant force on the footing passes through the middle–third portion of the base.
   (6) If the river bed consists of sand, it will be desirable to provide sheet piles on the upstream and downstream sides of the bridge.
   (7) It is not possible to know definitely the kinds of strata through which the test piles pass.
   (8) The cofferdam should be designed for the maximum water level and other destructive forces.
   (9) The percussion boring is not suitable for careful investigation.
   (10) The well foundation is favoured in our country.

Chapter 3

SUBSTRUCTURES

General:

The components of a bridge can be split up into *three* parts, namely, foundations, substructures and superstructures. The components designed to carry the total weight of the bridge are known as the *foundations*. The components of the bridge upto the level of bearings and above the level of bearings are respectively known as the *substructures* and the *superstructures*.

In this chapter, the substructures of a bridge will be discussed and the topic of superstructures will be covered up in the subsequent chapters 4 and 5.

Following are the *three* substructures of a bridge:

I. Abutments
II. Piers
III. Wing walls.

Each of the above substructure will now be discussed in detail.

I. Abutments:

Definition: The end support of a bridge superstructure is known as an *abutment*.

Functions: An abutment is provided for the following *three* purposes:

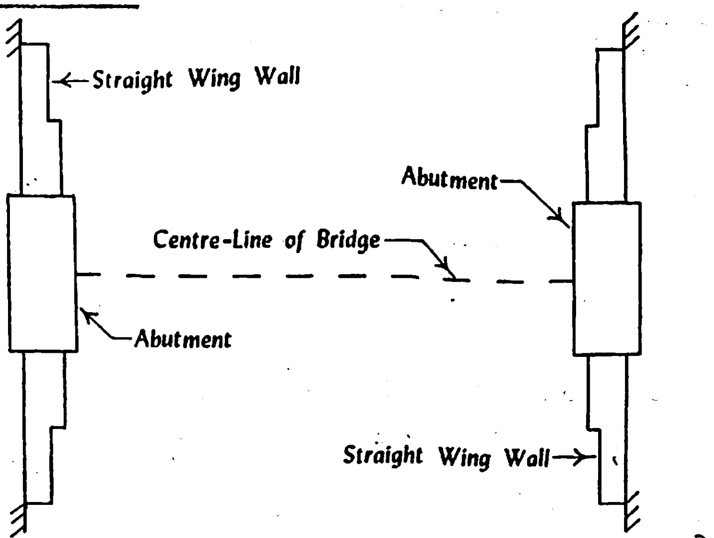
(1) to finish up to bridge so that it can be put for use;
(2) to retain the earth filling, and
(3) to transmit the reaction of superstructure to the foundations.

Types: The abutments are classified in the following *two* ways:

(1) According to the layout in plan
(2) According to the type of superstructure.

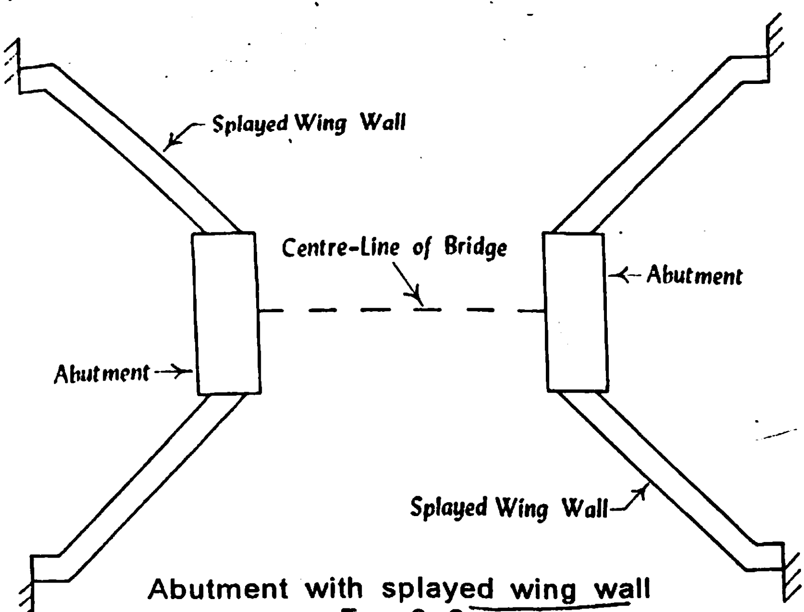
(1) *According to the layout in plan:* The abutments may be with or without the wing walls.

When the abutments are with wing walls, they may be of *three* types as shown in fig. 3–1 to fig. 3–3. Fig. 3–1 shows an abutment with straight wing walls. In this case, the wing wall is in line with abutment. Such an abutment is unsuitable for bridge with waterway as the flowing water is likely to damage the embankment behind the wing wall. Hence, such type of abutment is adopted for railway or street crossings.



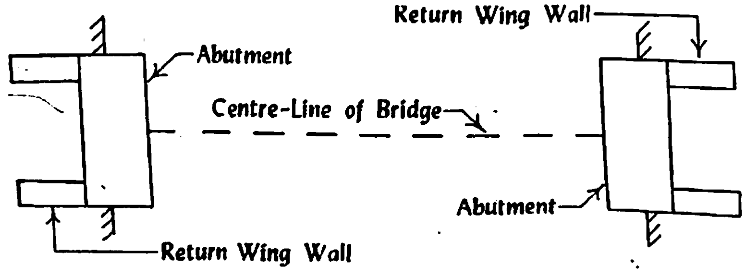
Abutment with straight wing wall (plan)
FIG. 3–1

Fig. 3–2 shows an abutment with splayed wing wall. Such an abutment is very common for the bridge with waterway as it permits smooth entry and exit of water under the bridge.



Abutment with splayed wing wall
FIG. 3–2

Fig. 3–3 shows an abutment with return wing wall and it is also referred to as U–abutment as it resembles the letter U in plan. In this case, the wing walls are parallel to the centre–line of bridge and such an abutment proves to be economical for rivers having steep and rocky banks and not subject to erosion.

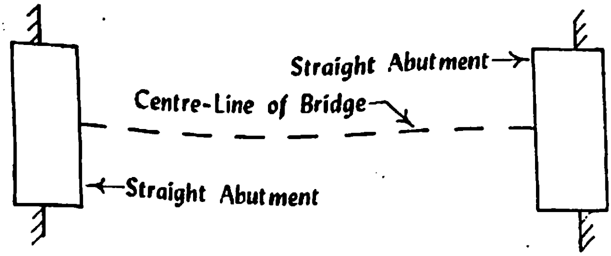


Abutment with return wing wall
FIG. 3–3

It is however not suitable for rivers or streams subjected to heavy floods as considerable portion of embankment outside the wing walls remains unprotected from the scouring action of water and it will not be safe because there is a tendency for the flood water to damage the embankment. The abutments with wing walls suffer from the following drawbacks:

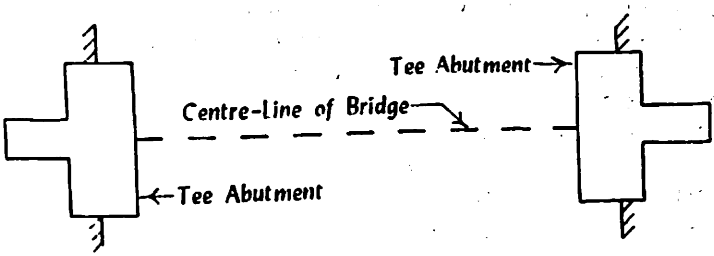
(i) It requires special care for the construction of connection between the abutment and wing walls to prevent cracks.

(ii) They tend to restrict the flood prism and hence, the scour is increased and the upstream flood level is raised. The increased depth of scour may require deeper foundations.



Straight abutment
FIG. 3–4

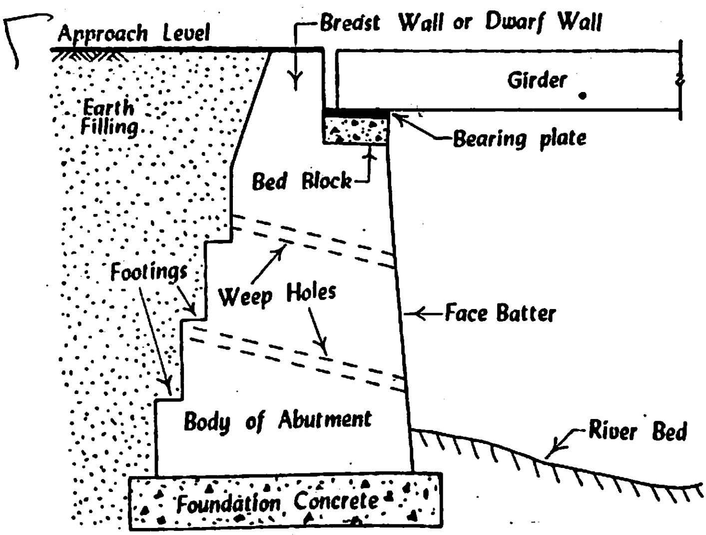
When the abutments are without the wing walls, they may be of *two* types as shown in fig. 3–4 and fig. 3–5. Fig. 3–4 shows a straight abutment without wing walls. Such an abutment will be useful for bridges without waterway or with negligible waterway.



Tee abutment
FIG. 3–5

Fig. 3–5 shows a tee or T–abutment as it resembles letter T in plan. The head of T–abutment supports the bridge and its stem carries the roadway for some distance be yond the embankment of river. It is usually not recommended because of the following *disadvantages*:

(i) It does not protect the embankment of river.
(ii) It gives a rigid formation over its stem portion.
(iii) It is uneconomical.
(iv) The quantity of masonry required for its construction works out to be more in proportion to its function.



Abutment of a girder bridge
FIG. 3–6

(2) *According to the type of superstructure:* The abutments may be provided for a girder bridge or an arch bridge.

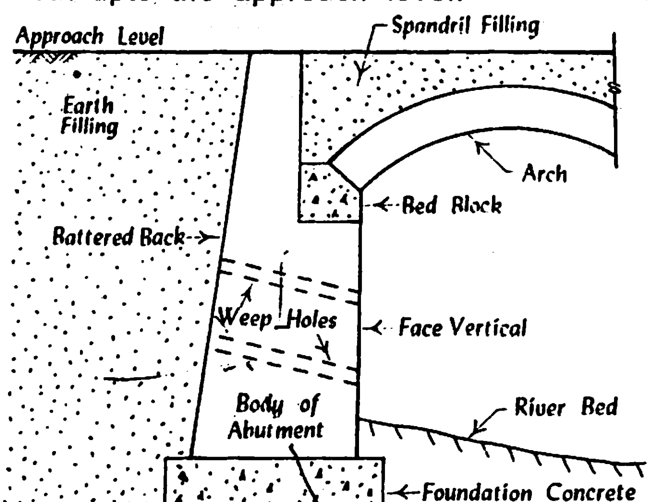
Fig. 3–6 shows a typical cross–section of an abutment for a girder bridge. A bed block of concrete is provided with a bearing plate to receive the end of girder. The breast wall or dwarf wall is constructed upto the approach level. The weep holes at different levels are provided to drain off water which gets access to the earth filling. They are provided at vertical intervals of 1 m and at horizontal spacings of 2 m. They are arranged in a staggered manner. The back side may be vertical or stepped. The face may be vertical or battered.

Table 3–1 shows the recommended face batter for different heights.

TABLE 3–1
FACE BATTER

No.	Height	Face batter
1.	Upto 6 m	Vertical
2.	6 m to 12 m	1 in 24
3.	12 m to 18 m	1 in 12
4.	Above 18 m	1 in 6

Fig. 3–7 shows a typical cross–section of an abutment for an arch bridge. The face is usually vertical. But it may be battered or stepped, if necessary. The spandrel filling is carried out upto the approach level.



Abutment for an arch bridge

FIG. 3–7

Forces acting on an abutment: Following forces in addition to its own dead weight act on an abutment:

(1) live load surcharge,
(2) pressure of earth filling,
(3) reaction from supersturcture,
(4) seismic load,
(5) tractive effort,
(6) water pressure, and
(7) wind load.

(1) *Live load surcharge:* The position of live load on earth which is retained by the abutment causes pressure on the abutment. The pressure so developed is uniformly distributed and it is known as the live load surcharge.

(2) *Pressure of earth filling:* The earth retained by the abutment causes pressure and the amount of earth pressure is worked out with the help of suitable formula.

(3) *Reaction from superstructure:* The reaction from superstructure is calculated and it may be vertical or inclined. Such a reaction includes the dead load of abutment, impact force and live load.

(4) *Seismic load:* If the bridge is located in earthquake zone, suitable allowance will have to be made for the seismic load in the design of abutment.

(5) *Tractive effort:* The forces developed by the application of brakes of vehicles which move on the superstructure of the bridge, are transmitted to the abutments through suitable bearings. The combined effect of such forces is known as the tractive effort.

(6) *Water pressure:* The effect of water pressure on an abutment is not appreciable and it is, therefore, usually neglected in the design of an abutment.

(7) *Wind load:* The wind also does not create appreciable effect on an abutment. Hence, it is the usual practice to neglect the wind load in the design of an abutment.

Conditions of stability: An abutment may fail either by crushing or overturning or sliding. Following conditions of stability should, therefore, be satisfied:

(1) *Crushing:* For masonry abutments, no tension should be developed at any section. For this purpose, it should be seen that the resultant of all forces above a particular section passes within the middle–third width of section. It

should also be ascertained that the compressive stress developed at all sections is less than the permissible load on the masonry.

(2) Overturning: If the balancing moment is not adequate, an abutment may overturn about the longitudinal axis or the transverse axis.

(3) Sliding: The resistance to sliding at all sections of the abutment should be more than the force tending to cause sliding of the abutment. The sliding of any horizontal section may take place either in the transverse or the longitudinal direction.

Considering the total load to be supported, type of superstructure, nature of flow, bearing capacity of soil and various other factors affecting the design of foundation, the dimensions and depth of the footing for the abutment should be carefully decided.

Dimensions: The various dimensions of an abutment such as batter, height, length and top width are decided as mentioned below. In general, it may be stated that the dimensions of an abutment should be decided by combining the theoretical approach with practical considerations.

(1) *Batter:* The face batter, if any, is provided as suggested in table 3–1. Sometimes, the uniform batter is provided on earth's side instead of footings. For arch bridges, the Trautwine's formula for batter on earth side is as follows:

$$\text{Batter on earth side} = 1 \text{ in } \frac{24 \times \text{rise}}{\text{span}}.$$

Thus, for an arch bridge having rise and span as 2.50 m and 15 m respectively

$$\text{Batter on earth side} = 1 \text{ in } \frac{24 \times 2.50}{15}$$
$$= 1 \text{ in } 4.$$

(2) *Height:* The height of an abutment is fixed up by the difference between the bed level of river banks and the formation level of the road or railway line.

(3) *Length:* The length of an abutment is represented by the overall width of the bridge including footpaths, if any. It also depends on the use of bridge. For a railway bridge, the length of an abutment will depend on the number of tracks, the gauge and the distance between the centre–line of tracks. For a road bridge, the length of an abutment will depend on the lanes of road.

(4) *Top width:* The top width of an abutment depends on the span of the bridge. But it should not be less than 500 mm in any case. For girder bridges, the top width should be sufficient to accommodate the bed block and breast wall. For arch bridges, the various empirical formulas are used. The Trautwine's formula, which is commonly used, is as follows:

$$E = \frac{r}{5} + \frac{a}{10} + 0.60$$

where E = top width in m

r = radius of soffit in m

a = rise in m.

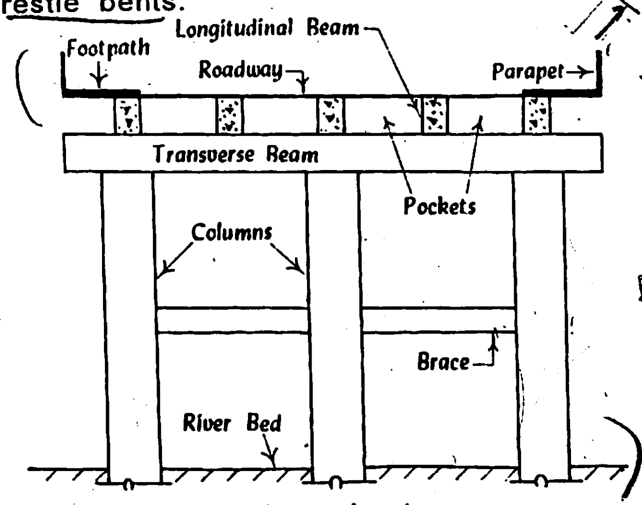
II. Piers:

Definition: The intermediate supports of a bridge superstructure are known as the *piers*.

Function: The only purpose of providing piers is to divide the total length of bridge into suitable spans with minimum obstruction to the stream or river.

Types: Following are the usual types of the bridge piers:

(1) Column bents
(2) Cylinder piers
(3) Dumb-bell piers
(4) Pile bents
(5) Solid piers
(6) Trestle bents.

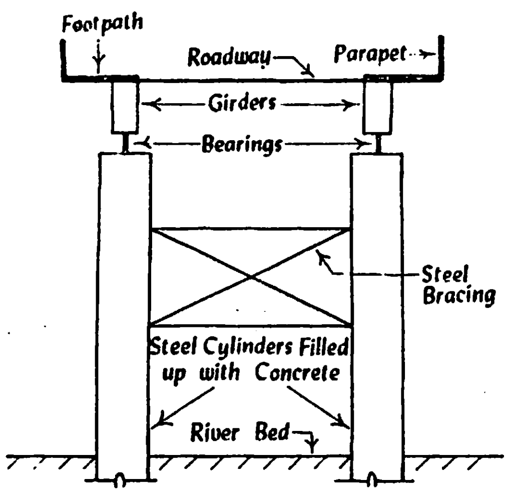


Column bents
FIG. 3–8

(1) *Column bents:* A column bent type of pier is adopted, if the longitudinal beams or girders of the superstructure of bridge are closely spaced. The term bent is used to indicate a supporting frame consisting of vertical members and braces. The transverse beams are provided to support the longitudinal beams and two or more columns on a solid foundation are constructed to support the transverse beams as shown in fig. 3–8.

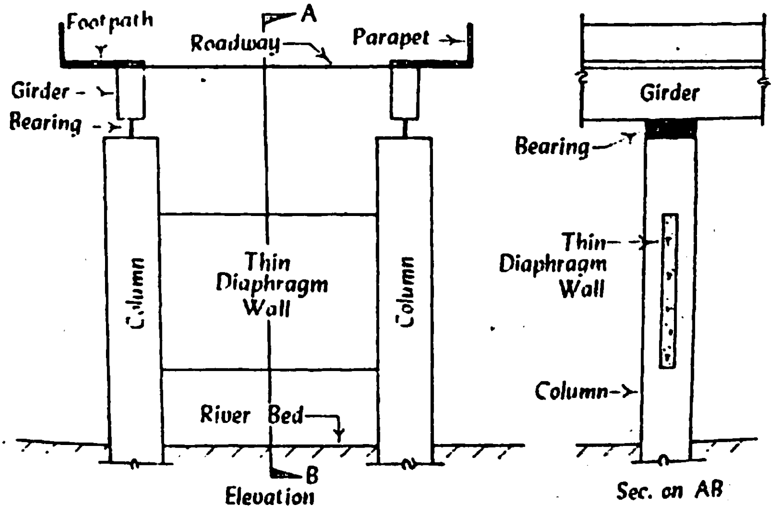
The pockets formed between the longitudinal beams may be used to carry gas pipes, sewage pipes or water pipes. The column bents are lighter than the masonry piers and are used for continuous spans.

(2) *Cylinder piers:* A cylinder pier consists of mild steel cylinders connected by the horizontal and diagonal bracings as shown in fig. 3–9. These piers are adopted when foundations are of steel cylinder caisson type. The concrete is poured in the steel cylinders after being sunk and they support the girders of the bridge through suitable bearings.

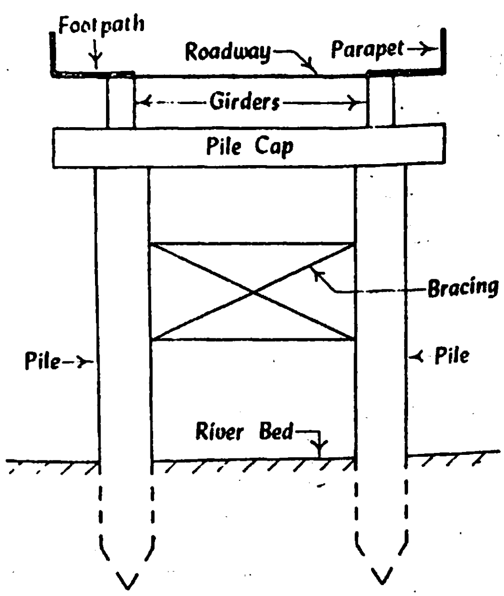


Cylinder pier
FIG. 3–9

(3) *Dumb–bell piers:* A dumb–bell pier has an appearance of a dumb–bell i.e. a weight for exercises, in plan. It is adopted when the superstructure of bridge is supported on the twin girders. A column is provided below each girder and the columns are connected by thin diaphragm wall along their height as shown in fig. 3–10.



Dumb–bell pier
FIG. 3–10



Pile bent
FIG. 3–11

Following are the *advantages* of the dumb–bell piers:

(i) As compared to its mass, a dumb–bell pier gives maximum moment of inertia.

(ii) The design of dumb-bell piers is simple and it leads to the light reinforcement.

(iii) They are light in weight as compared to the solid mass concrete piers.

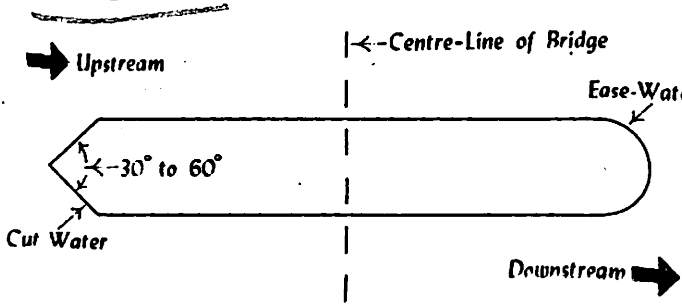
(iv) They are very much suitable when the well foundations are adopted.

(4) *Pile bents:* In case of pile bents, the girders of superstructure of bridge are supported on R.C.C. or steel piles. A pile cap is provided to connect piles at the top and they are suitably braced along their height as shown in fig. 3–11. The pile bents are used for low piers over unstable or muddy ground.

(5) *Solid piers:* In case of solid piers, the piers consist of the masonry or cement concrete of solid section throughout the entire length of pier. Such type of construction of piers is very popular in the bridge construction, mainly for *two* reasons:

(i) It can be used for any type of superstructure of the bridge.

(ii) It provides excellent resistance to the actions of floating bodies.



Cut–water and ease–water
FIG. 3–12

The ends of solid piers may be rectangular. But they may be given any suitable shape to make the entry and passage of water easy and smooth. The end or nose of pier on upstream side is known as the *cut-water* and that on downstream side is known as the *ease-water* as shown in fig. 3–12.

The cut–waters are usually triangular in shape. The cut–waters need not be very long and they should be carried down to the base. The ease–waters are usually semi–circular or they may consist of *two* parabolic arcs.

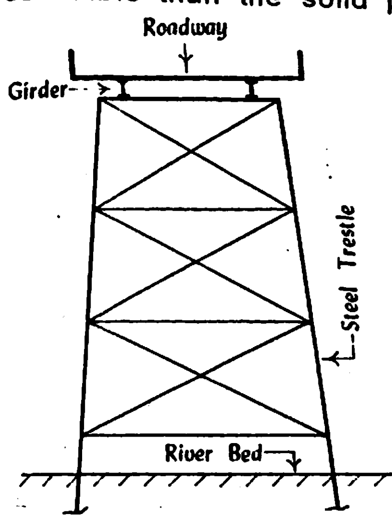
If, at the time of floods, there are chances of damage to cut–waters, due to striking of floating debris, the noses of cut–waters may be protected by fixing steel angles. The provision of cut–water and ease–water in the structure of solid piers results in the following *advantages:*

(i) The eddying effect of current of water is minimized.

(ii) The effect of horizontal pressure due to the current of water is reduced.

(iii) The natural movement of the water is disturbed to the minimum possible extent.

(6) *Trestle bents:* A trestle is a framed pier and it consists of vertical, horizontal and diagonal members as shown in fig. 3–13. The trestle bents may be of steel or concrete, the former being very common. The trestle bents are useful for constructing piers for a bridge along a viaduct or in case of flyovers and elevated roads. A deep valley having non–perennial stream or river is known as a *viaduct*. The trestle bents with considerable height and narrow roadway are usually inclined for additional stability, as shown in fig. 3–13. The wide base at bottom resists wind pressure in a better way. The inclination is about 1 in 4 to 1 in 8 i.e. 250 mm to 125 mm per metre height. The trestle bents are suitable only where the channel bed is fairly firm and not suited to rapid streams on stony beds. They induce scour which can be reduced by providing pitching in the bed. They are less stable than the solid piers.



Trestle bent
FIG. 3–13

Forces acting on a pier: Following forces in addition to its own dead weight act on a pier:

(1) reaction from superstructure,
(2) seismic load,
(3) tractive effort,
(4) water pressure, and
(5) wind load.

(1) *Reaction from superstructure:* This force is the same as in case of an abutment.

(2) *Seismic load:* This force is the same as in case of an abutment.

(3) *Tractive effort:* This force is the same as in case of an abutment.

(4) *Water pressure:* The pressure on pier due to water consists of the following *three* types:

(i) dynamic effect developed due to the velocity of water;

(ii) impact pressure developed due to the cross–currents which are set up near the bottom of pier; and

(iii) static pressure due to the head of water.

(5) *Wind load:* The effect of wind on moving loads and on the superstructure on pier height above water level is worked out.

In some cases, the pier will also have to resist the following forces:

(1) buoyancy of submerged part of the substructure which can be neglected for piers anchored to rocks by the dowels;

(2) force due to collision of the vessels in the navigable rivers; and

(3) longitudinal force due to resistance in bearings.

Conditions of stability: The conditions of stability for a pier are the same as those mentioned in case of an abutment.

Dimensions: The various dimensions of a pier such as batter, height, length and top width are decided as mentioned below. In general, it may be stated that the dimensions of a pier should be decided by combining theoretical approach with practical considerations.

(1) *Batter:* In some cases, the sides of a masonry pier are provided with uniform batter. The value of batter varies from 1 in 12 to 1 in 24. The greater value is usually adopted for low piers and the smaller value is usually adopted for high piers.

(2) *Height:* The height of a pier is fixed up by the difference between the level of river bed and the formation level of the road or railway line. It should, however, be seen that sufficient freeboard or clearance to the extent of about 1000 mm to 1500 mm is maintained between the bottom of superstructure and the highest flood level (for non–submersible bridges) or normal flood level (for submersible bridges).

(3) *Length:* The length of a pier should be at least equal to the width of bridge (excluding cantilever projections, if any) plus the widths of cut–water and ease–water.

(4) *Top width:* The top width of a pier depends on span. But it should be sufficient to accommodate two bearings for the pier with a clearance of about 150 mm. In any case, it is the usual practice to provide a minimum width of about 750 mm.

Location: The location of piers or spacing of piers should be carefully decided by considering the following important requirements:

(1) It is desirable to have the piers nearly parallel to the direction of the flow of river.

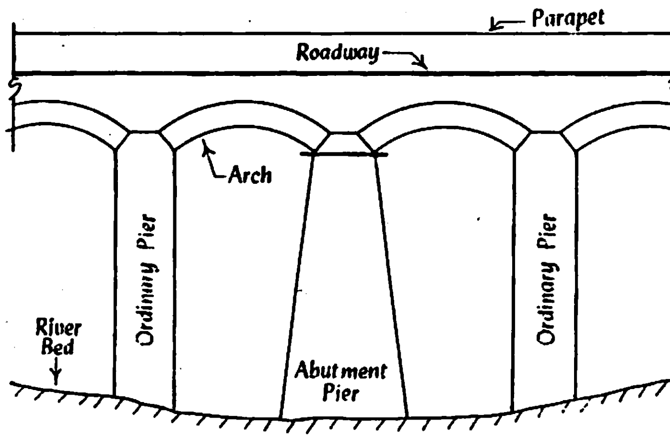
(2) The piers should be located in such a way that they cause the least obstruction to the flow of water.

(3) The piers should rest on the solid and stable foundations. For this purpose, the results obtained from trial pits or boring along the length of bridge should be properly studied and analysed.

Abutment pier: In case of an arch bridge having a number of spans, every fourth or fifth pier is designed to resist the inclined reaction due to dead load on one side and no load on the other side. Such a pier is known as an *abutment pier* as shown in fig. 3–14 and it is of bigger dimensions than the ordinary piers. The provision of an abutment pier affords the following *two* advantages:

(1) The construction work of arch bridge can be carried out in sections. It proves to be speedy and economical.

(2) The effect of any failure of an arch due to earthquake or flood or any other reason can easily be localized, when an abutment pier is provided. Such an effect does not extend from one end of the bridge to the other. But it stops at the abutment pier.



Abutment pier
FIG. 3–14

III. Wing walls:

Definition: The abutment can be either buried or its front face can be left exposed. In the latter case, the walls constructed on either side of an abutment to support and protect the embankment are known as the *wing walls.*

Functions: A wing wall has mainly to perform the following *two* functions:

(1) to provide a smooth entry into the bridge site; and

(2) to support and protect the embankment.

Types: Following are the *three* types of wing walls.;

(1) Straight wing wall

(2) Splayed wing wall

(3) Return wing wall.

Each of the above type of wing wall will now be briefly described.

(1) *Straight wing wall:* When the wing walls are constructed in line with the abutment, as shown in fig. 3–1, they are known as the *straight wing walls*. Such type of wing wall is found to be economical when there is no danger of washing of the material from the bank of river. This type of wing wall is suitable for small bridges which are constructed across the drains having low banks.

(2) *Splayed wing wall:* When wing walls are given inclination in plan, as shown in fig. 3–2, they are known as the *splayed wing walls*. The wing walls may also be curved, instead of being splayed. The splay or inclination is usually 45° and such types of wing walls offer the following *three* advantages:

(i) It is not necessary for the splayed wing walls to have additional protections such as rubble filling and pitching of the embankment.

(ii) The height of splayed wing wall may be changed from point to point along its length. It may have minimum height at the far end from the abutment and maximum height equal to that of the abutment at the end near the abutment. Such an arrangement reduces the cost of splayed wing wall.

(iii) They provide smooth entry and exit to the flowing water.

The splayed wing walls are best suited when the width of road is to be reduced while crossing the bridge or at places where two or more roads meet at the approach.

(3) *Return wing wall:* When angle of splay becomes 90°, as shown in fig. 3–3, the wing walls are known as the *return wing walls*. Such wing walls are preferred to the splayed wing walls in case of very high embankments. When the return wing walls are adopted, it is possible to suitably extend the parapet walls on either side of the bridge beyond the abutment. The return wing walls are taken sufficiently inside so that the earth slope along them terminates outside the waterway. These walls confine the formation of the approaches and add to their strength.

Forces acting on a wing wall: Following forces act on a wing wall:

(1) dead load,
(2) live load surcharge,
(3) pressure of earth filling,
(4) seismic load, and
(5) water pressure.

(1) *Dead load:* The dead load indicates the weight of wing wall and it depends on the material of which the wing wall is composed.

(2) *Live load surcharge:* This force is the same as in case of an abutment.

(3) *Pressure of earth filling:* This force is the same as in case of an abutment.

(4) *Seismic load:* This force is the same as in case of af abutment.

(5) *Water pressure:* The effect of water pressure on a wing wall is not appreciable and it is, therefore, usually neglected in the design of a wing wall.

Conditions of stability: The conditions of stability for a wing wall are the same as those mentioned in the case of an abutment.

Dimensions: The various dimensions of a wing wall such as batter, height, length and top width are decided as mentioned below. In general, it may be stated that the dimensions of a wing wall should be decided by combining the theoretical approach with practical considerations.

(1) *Batter:* The sides of wing walls may be provided with uniform batter. The value of batter may vary from 1 in 4 to 1 in 12. In case of return wing wall, the face is kept vertical.

(2) *Height:* The height of wing wall should be sufficient to retain the earth filling. It is possible to vary the height of wing wall from point to point as in case of the splayed wing walls.

(3) *Length:* The shortest length which will allow wing wall to function properly is worked out by considering the following *three* levels:

(i) bed level of river or stream,

(ii) formation level of road or railway line, and

(iii) natural ground level of embankment.

In practice, the contour plan of the bridge site is drawn and from it, the correct economic length of wing wall is worked out. The wing walls should always be founded on the natural ground and they should not be made longer than required. They should permit the earth of the approach filling to be trimmed to its natural slope.

(4) *Top width:* The top width depends on the type of wing wall. But in any case, it should not be less than 500 mm.

Precautions: Following *two* precautions should be taken during the construction of wing walls:

(1) *Gap:* The wing walls are rarely designed to take part of abutment load. In that case, they are rigidly connected with the abutment. In all other cases, the wing walls and abutments act independently. It is, therefore, most essential to have a clear gap of about 6 mm width between these two structures and this gap is then sealed by bitumen.

(2) *Weep holes:* To drain off water which gets access to the earth filling, sufficient weep holes should be provided in the body of wing walls as in case of the abutments.

Setting out for piers and abutments:

It is important to see that the positions of the piers and abutments are carefully set out. It is also necessary to check them periodically during construction for ensuring proper alignment and centre–to–centre distance. If this precaution is not taken, the girders may not fit at the time of final laying in position unless they are to be cast–in–situ. In the latter case also, it may result in one span becoming longer than the designed span and may require strengthening.

Each setting out problem will have to be tackled in its own way. Following are some of the guide lines to be observed in the setting out process;

(1) *Bench marks:* It is desirable to use the existing GTS bench marks for reference, wherever possible. If it is not possible to refer to the GTS bench marks, suitable additional bench marks connecting to the GTS bench marks may be carefully established.

(2) *Positions of reference points:* The positions of principal reference lines and level pegs should be selected in such a manner that they can remain in an accessible position during the progress of work. They should also be readily visible and should be in such a position that they are not disturbed until at least the abutments have been built. It should also be possible to transfer them on the completed abutments.

(3) *Principal reference lines:* For a bridge, the principal reference lines are the longitudinal centre–line and the transverse centre–line. For a bridge on curve, the tangent points of the curve should be established by pegs and also by pegs which are provided to define the direction of the tangents.

(4). *Replacing original points:* If the original points are disturbed due to any reason during the progress of work, they should be carefully replaced and checked before the original points are removed or covered.

Materials for substructures:

Following are the *three* common materials of construction for the various substructures:

(1) Cement concrete

(2) Masonry

(3) Steel.

(1) *Cement concrete:* The mass cement concrete is an ideal material for various substructures. The usual proportion of cement concrete is M 10 or 1:3:6 i.e. one part of cement, three parts of fine aggregate and six parts of coarse aggregate by volume. If it is desired to save in the quantity of concrete, the use of displacers or large blocks of stones is recommended.

Where tension is likely to occur, the reinforcement is placed in cement concrete and it is then referred to as reinforced cement concrete or R.C.C. construction. The abutments and wing walls of R.C.C. may be designed with or without counterforts. The beams placed at suitable spacing for support are known as the counterforts. For R.C.C. piers, the main reinforcement is vertical and secondary reinforcement is in the form of rings which bind the main reinforcement.

The pre–stressed concrete can also be used for piers particularly on viaducts with tall piers. The mix to be adopted should be according to the design requirement.

(2) *Masonry:* The substructures may be constructed either of brick masonry or stone masonry. Following points should be noted:

(i) For small spans, the brick masonry is preferred. But for large spans, the stone masonry is adopted.

(ii) The mortar used in the construction of stone or brick masonry should be of sufficient strength. The leanest proportion of the mortar to be used is of proportion (1:4).

(iii) The stone masonry is adopted where good stones are easily available and the brick masonry is adopted where good bricks are available. If the river carries moving debris, the bridge structure of brick is damaged considerably affecting its strength and with age, the appearance also suffers.

(3) ***Steel:*** The steel can only be used for the piers and it is generally used in the construction of the trestle bents.

In general, it should be observed that while selecting the type of material for the substructure, the relative merits and demerits with regard to the economy in material and the difficulty in construction should be suitably analysed alongwith the aesthetic requirements.

Bridge Inspection:

The main aims of bridge inspection are assurance of safety, economic planning and protection of national wealth.

Following are the main objectives of bridge inspection:

(1) Budgeting of available funds.

(2) Identification of actual sources of deficiencies at the earliest possible stage.

(3) Planning of classification of bridges, maintenance, repair and reconstruction activities, traffic regulations, etc.

(4) Providing information to the researchers, designers and construction agencies regarding performance of materials, design criteria, construction techniques and new areas requiring research, development and standardization.

The existing system of bridge inspection in India is based on the Manual for Maintenance and Inspection of Bridges published in 1978 by Indian Road Congress. The frequency of inspection is recommended as once in a year.

QUESTIONS

1. What are the substructures of a bridge? Mention the functions of each of them.
2. Discuss the various types of abutments.
3. What are the forces acting on an abutment?
4. Define the following:

   Abutment; Pier; Wing wall; Abutment pier; Cut–water; Ease–water.
5. What are the conditions for stability of substructures?

6. Explain how the following dimensions are decided in case of abutments piers and wing walls:

   Batter, Height, Length, Top width.

7. Describe the usual types of bridge piers.

8. What are the advantages of dumb–bell piers?

9. Mention the forces acting on a pier.

10. How is the location of piers decided?

11. Write short notes on:

    (1) Abutment pier
    (2) Trestle bents
    (3) Tee abutment
    (4) Splayed wing wall
    (5) Column bents
    (6) Solid piers.

12. Explain the various types of wing walls.

13. State the forces acting on a wing wall.

14. What are the precautions to be taken during the construction of wing walls?

15. Explain the importance of setting out for piers and abutments and suggest some guide lines for the same.

16. Write a brief note on the materials of construction for the substructures.

17. What are the aims and objectives of bridge inspection?

18. Give sketches of the following:

    (1) Abutment for a girder bridge
    (2) Abutment for an arch
    (3) Dumb–bell pier
    (4) Cylinder pier.

19. Differentiate between the following:

    (1) Foundations, substructures and supersturctures
    (2) Abutment and pier
    (3) U–abutment and T–abutment
    (4) Cylinder piers and solid piers
    (5) Cut–water and ease water
    (6) Pile bent and trestle bent
    (7) Straight, splayed and return wing walls.

20. Give reasons for the following:

(1) An abutment with the straight wing wall is unsuitable for bridge with waterway.

(2) An abutment with the splayed wing wall is very common for bridge with waterway.

(3) The Tee abutment is usually not recommended.

(4) Sufficient weep holes are provided in the body of abutments and wing walls.

(5) The solid piers are very popular in the bridge construction.

(6) The provision of cut–water and ease–water is desirable in the structure of solid piers.

(7) In case of an arch bridge having a number of spans, the abutment piers are provided.

(8) The water pressure and wind load are usually neglected in the design of an abutment.

(9) The cost of a splayed wing wall is less.

(10) The return wing walls are taken sufficiently inside.

(11) It is important to see that the positions of the piers and abutments are carefully set out.

Chapter 4

FIXED–SPAN SUPERSTRUCTURES

General:

The superstructure of a bridge can broadly be classified into *two* categories, namely, fixed–span superstructure and movable–span superstructure.

In case of fixed–span superstructures, the superstructure remains in a fixed position and most of the bridges are of this category. In case of movable–span superstructures, the superstructure is lifted or moved with the help of some suitable arrangement.

In this chapter, the bridges with the fixed–span superstructures will be discussed and the bridges with the movable–span superstructures will be discussed in the next chapter.

Following are the various types of bridges with the fixed–span superstructures:

I. Simple bridges
II. Continuous bridges
III. Cantilever bridges
IV. Arch bridges
V. Bow–string girder type bridges
VI. Rigid frame bridges
VII. Suspension bridges
VIII. Cable–stayed bridges.

I. Simple bridges:

In case of simple bridges, the span is simply supported and they are sometimes referred to as the *independent–span bridges*. Depending upon the position of superstructure, the simple bridges are divided into the following *three* categories:

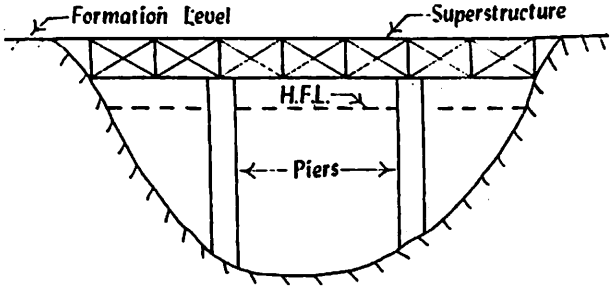
(1) Deck bridges
(2) Through bridges
(3) Semi–through bridges.

(1) *Deck bridges:* For any bridge, the following *two* levels are to be carefully decided:

(i) *Formation level:* The ground level of approaches is to be taken into consideration for fixing the formation level of road or railway line.

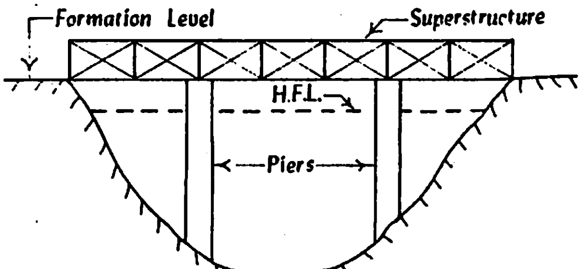
(ii) *Highest flood level or H.F.L.:* While making the calculations for maximum flood discharge, the H.F.L. for the river or stream is determined.

If it is possible to accommodate the superstructure of bridge between these *two* levels with suitable allowance for clearance, as shown in fig. 4–1, the bridge is known as the *deck bridge*.



Deck bridge
FIG. 4–1

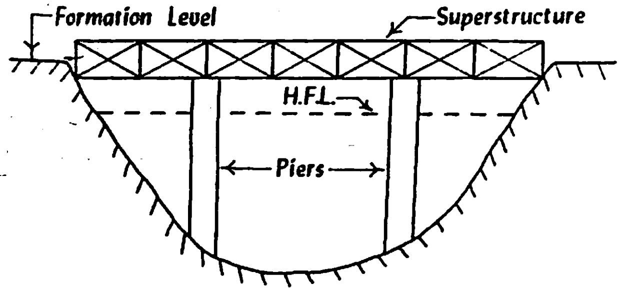
(2) ***Through bridges:*** Sometimes the difference between the formation level and H.F.L. is not sufficient to accommodate the superstructure of bridge. In such cases, the superstructure projects above the formation level, as shown in fig. 4–2. Such a bridge is known as the *through bridge*.



Through bridge
FIG. 4–2

(3) ***Semi–through bridges:*** When the superstructure of bridge projects partly above the formation level and partly below the formation level, as shown in fig. 4–3, it is known as the *semi–through bridge* and it is thus an intermediate type between the deck bridge and through bridge.

Out of *three* types of simple bridges, the deck type proves to be economical. Following are the *advantages* of a deck bridge:



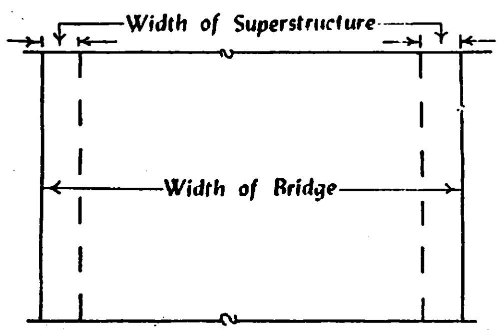
Semi–through bridge
FIG. 4–3

(i) *Effect of horizontal forces:* The effect of various horizontal forces such as tractive effort and wind load will be comparatively less on a deck type bridge than that on a through type bridge. The deck bridge gets this advantage as its superstructure is situated below the formation level of road or railway line.

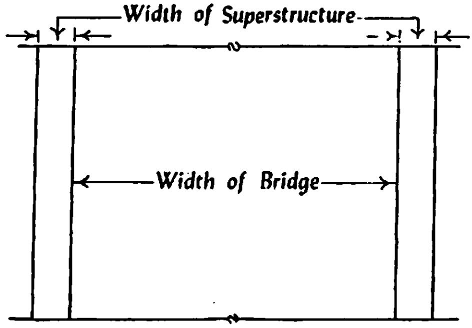
(ii) *Erection:* For steel bridges, it proves to be easier to erect the superstructure of a deck bridge than that of a through bridge.

(iii) *Natural scenery:* A deck bridge grants better view of the surrounding scenery and hence, it is preferred to the through bridge for carrying the highway traffic.

(iv) *Width of bridge:* The total width of a deck bridge will be equal to its actual width, as shown in fig. 4–4. The total width of a through bridge will be equal to the actual width of bridge plus width of superstructure on either side, as shown in fig. 4–5. Thus, the total width of a through bridge will be more than that of a deck bridge. Hence, for the same width of bridge, the weight of superstructure in case of through bridge will be more than that of a deck bridge.



Plan of deck bridge
FIG. 4–4



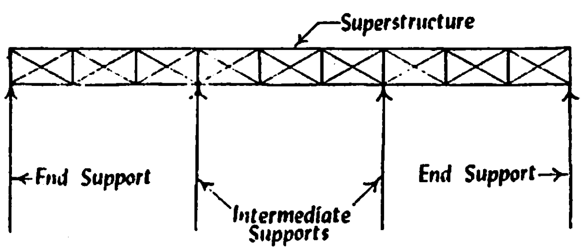
Plan of through bridge
FIG. 4–5

II. Continuous bridges:

When the bridge is designed to continue unbroken over intermediate supports, it is said to be continuous bridge. Fig. 4–6 shows a continuous bridge.

When the design of a bridge is made on a continuous span, it is found that the bending moment anywhere in the span is considerably less than that in case of a simply supported span. Such reduction of bending moment ultimately results in the economic section for the bridge. But to take maximum advantage of a continuous span, it is essential that the following *two* conditions are satisfied:

(1) Facilities for erection
(2) Hard soil.



Continuous bridge
FIG. 4–6

(1) ***Facilities for erection:*** For steel bridges, the girder for continuous span will be of a fairly heavy weight. Hence, it is necessary to have suitable facilities at bridge site to erect such girders.

(2) ***Hard soil:*** A continuous bridge is an indeterminate structure. Hence, a slight sinking of any support considerably alters the designed values of bending moment and shear force at various sections along the span of bridge. It is, therefore, necessary to check that the foundations of supports rest on hard and firm soil. At places where there are chances for foundation to sink or settle, the continuous bridges are not adopted.

Following are the *advantages* of R.C.C. continuous girder bridges over simply supported girder bridges:

(1) As the bearings are placed on the centre–lines of piers, the reactions at piers are transmitted centrally.

(2) It is found that the continuous girder bridge suffers less vibration and deflection.

(3) The continuous girder bridge requires only one bearing at each pier as against two bearings for simply supported girder bridge.

(4) The depth of decking at midspan is reduced and it may prove to be useful for overbridges where the headroom is of prime consideration.

(5) The expansion joints required will be less.

(6) There is reduction in cost as less quantities of concrete and steel are required.

Following are the *disadvantages* of R.C.C. continuous girder bridges over simply supported girder bridges:

(1) The design is more complicated as it is a statically indeterminate structure.

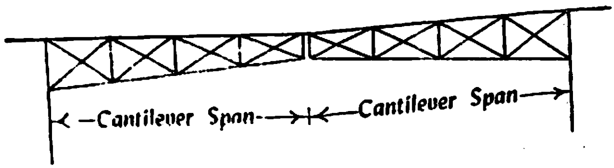
(2) The detailing and placing of reinforcements are to be carried out with extreme care.

(3) The placing of concrete and removal of formwork are to be executed carefully in proper sequence.

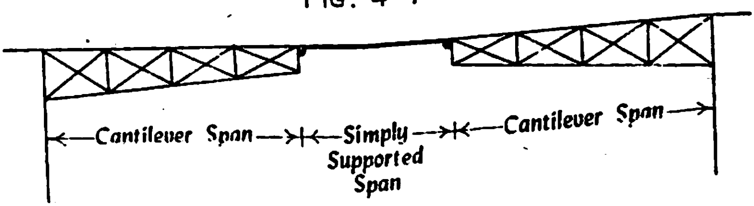
III. Cantilever bridges:

A cantilever bridge is formed of the cantilevers projecting from the supporting piers. The ends of a cantilever bridge are treated as fixed. A cantilever bridge combines the advantages of a simply supported span and a continuous span. For long spans and deep valleys and at places where it will not be practicable to use centering, the cantilever bridges are more suitable.

The construction of a cantilever bridge may either b of simple type or of balanced type. Fig. 4–7 shows cantilever bridge with simple construction. The ends cantilever just meet at the centre of span. Fig. 4–8 shows a cantilever bridge with balanced type of construction. In this case, the hinges are provided at the points of contraflexure of a continuous span and an intermediate simply supported span is suspended between these *two* hinges.

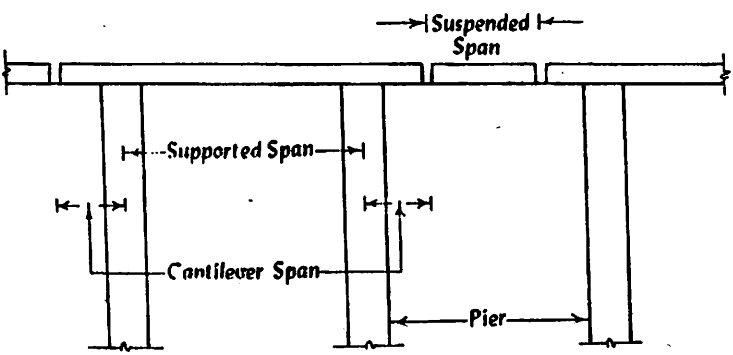


Cantilever bridge with simple construction
FIG. 4–7



Cantilever bridge with balanced type construction
FIG. 4–8

A modified form of this type can be constructed in R.C.C. with two cantilevers on either side of the pier and providing a suspended span as shown in fig. 4–9. The size and shape of the counter–weighted cantilevers are determined after trying several possible combinations. The usual length of cantilever span is about one–fifth to one–third of the main supported span.



Bridge with counter–weighted cantilevers
FIG. 4–9

However, this type of construction demands extreme care and skill in its design and elaborate detailing of reinforcements. But it affords the various *advantages* over simply supported construction such as fewer expansion bearings, reduction in quantity of steel and concrete, piers of moderate dimensions, lower initial and maintenance costs, etc.

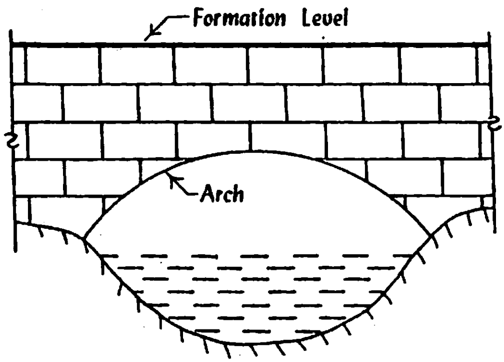
IV. Arch bridges:

In case of arch bridges, the road or railway track is carried on arches. The rise of the arch is kept as large as possible so as to reduce the horizontal thrust and to economise on the design of the piers, abutments and foundations. It is usually kept not less than one–third span, but in no case less than one–fifth span. It is also desirable to choose a simple shape for the arch. It will facilitate its setting out and construction.

Classification of arches: The bridge arches are classified as follows:

(1) according to condition of spandrel,
(2) according to number of hinges,
(3) according to shape, and
(4) according to width.

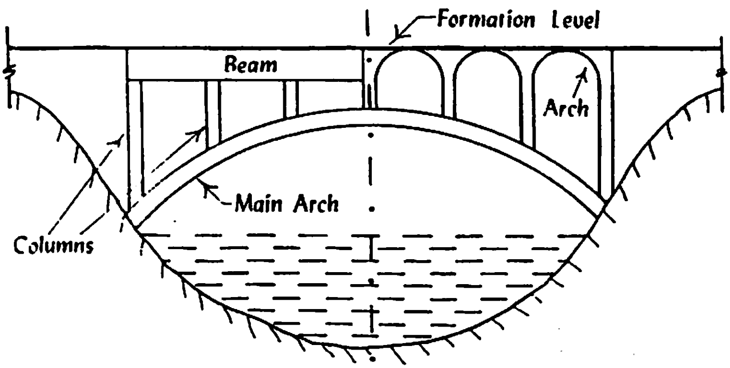
(1) *According to condition of spandrel:* Depending upon the condition of space above the arch and below the formation level, the arches are classified as *filled spandrel arch* and *open spandrel arch*.



Filled spandrel arch
FIG. 4–10

Fig. 4–10 shows a filled spandrel arch. The side walls are taken upto the bottom of formation level and the interior portion is filled up either by earth or any other suitable filling material upto the road formation level. A filled spandrel arch is suitable when ratio of rise to span is small. If rise to span ratio is above a certain limit, a filled spandrel arch proves to be uneconomical as it will require excessively heavy side walls and considerable amount of filling.

Fig. 4–11 shows an open spandrel arch. The flooring of bridge is supported either by beams and columns or by arches and columns. The main arch supports the columns. The space between the columns is kept open. This type of arch is aesthetically good and it provides a beautiful structure specially in a narrow valley or gorge.



Open spandrel arch
FIG. 4–11

An open spandrel arch is suitable when ratio of rise to span is high and it proves to be economical because of the following reasons:

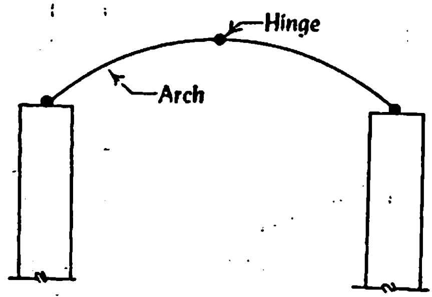
(1) There is considerable reduction in the dead load of the structure as the filling material is not required. It will thus reduce the costs of arch and foundation.

(2) The main arch may be made of rib type and two or more independent narrow ribs may be provided to support the bridge. Further, these ribs may be made deeper and they may be suitably reinforced. All such measures will result in the reduction of bending moments and tensile stresses.

(2) *According to number of hinges:* Depending upon the number of hinges provided, the arches are classified as *three–hinged arch, two–hinged arch, one–hinged arch* and *hingeless* or *fixed arch*.

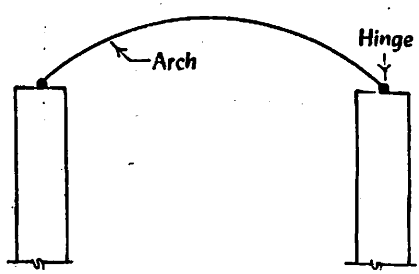
Fig. 4–12 shows a three–hinged arch. It contains hinges at crown and springing points. A three–hinged arch is structurally stable and is adopted when it is difficult to obtain hard soil within a reasonable depth or where the foundations are likely to yield.

The *disadvantage* of this type of bridge is that the thickness at the quarter points is more than that at spring. Hence, the masking is required for aesthetic purposes. The three–hinged arches are sometimes provided only while using the steel arches.



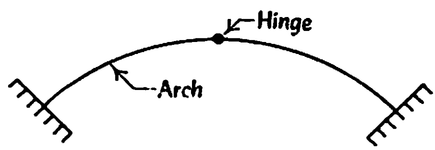
Three–hinged arch
FIG. 4–12

Fig. 4–13 shows a two–hinged arch. It contains hinges at the supports i.e. pier or abutment. The two–hinged arches are simple for analysis as there is no bending moment at the support and only reactions are transmitted to the supports. They are easily adaptable for the construction of concrete and steel arches. The bow–string girder arch in R.C.C. is also treated like a two–hinged arch for the purpose of design.



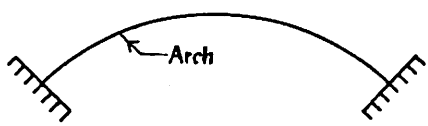
Two–hinged arch
FIG. 4–13

Fig. 4–14 shows a one–hinged arch. It contains only one hinge at the crown.



One–hinged arch
FIG. 4–14

Fig. 4–15 shows a fixed arch. It does not contain any hinge. It is adopted where hard unyielding soil is available for the supports of an arch. It is the most commonly employed arch especially in masonry and it provides a very good aesthetic appearance. It is, however, difficult for analysis. But it is economical and can be adopted for long spans also.



Fixed arch
FIG. 4–15

(3) *According to shape:* The bridge arches can also be classified according to the shape of arch. The commonly adopted shapes of bridge arches are semi – circular, segmental, pointed, semi–elliptical and multi–centered. At places where sufficient height is available, the pointed or semi–circular shapes can be adopted.

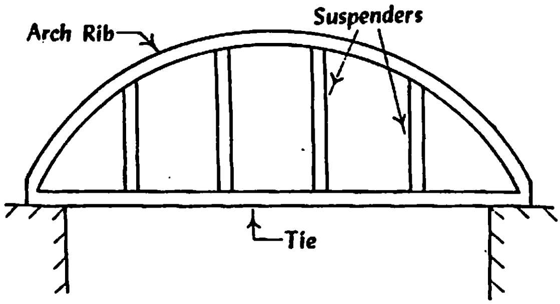
For medium span lengths, the segmental or parabolic profiles will be more appropriate. For long spans, the multi–centered shapes are found to be convenient.

(4) *According to width:* Depending upon the width of arch in the transverse direction of bridge, the arches are classified as *barrel type* or *rib type*.

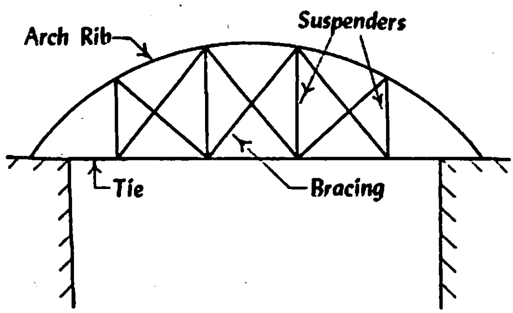
Fig. 4–16 shows a barrel type arch bridge. The widths of arch and bridge are the same and it results in the formation of a barrel.

The bow–string girder type bridges are therefore very suitable for multiple spans and at places where the available clearance is restricted.

Fig. 4–18 shows an R.C.C. bow–string girder bridge and it can be adopted for spans of 30 m to 45 m.



R.C.C. bow–string girder bridge
FIG. 4–18



Steel bow–string girder bridge
FIG. 4–19

Fig. 4–19 shows a steel bow–string girder bridge and it can be adopted for spans of 120 m to 240 m.

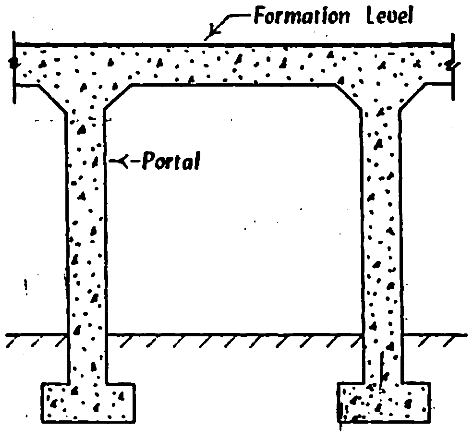
VI. Rigid frame bridges:

In case of rigid frame bridges, the monolithic portal frames are designed for the superstructure and substructure.

Following are the favourable conditions for a rigid frame bridge:

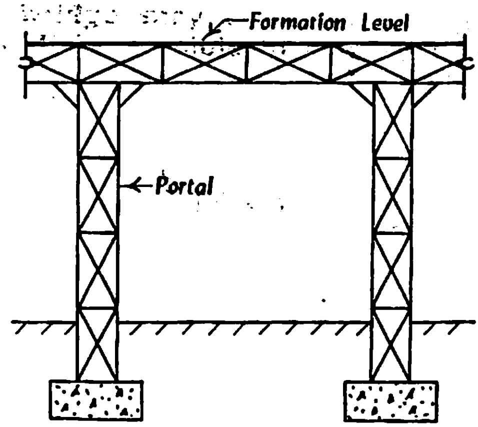
(1) It is not possible to provide an arch bridge.
(2) The bearing capacity of soil is low.
(3) There is restriction of headroom over the full span.
(4) The roadway is wide.
(5) The span is small.

Fig. 4–20 shows an R.C.C. portal frame. Suitable reinforcement may be provided as required. The bridge may consist of single portal or continuous portals. The R.C.C. portal frames are suitable for spans upto 15 m or so.



R.C.C. portal frame
FIG. 4–20

Fig. 4–21 shows a steel frame. It may suitably be braced as required. The bridge may consist of single portal or continuous portals. It is possible to construct steel portals in short time and they are suitable at places where the cost of construction for the abutments is high.



Steel portal frame
FIG. 4–21

In addition to the advantages offered by the continuous bridges, the rigid frame bridges grant the following additional advantages:

(1) As the connections are rigid, it gives more stability to the supports as compared to independent piers of the same dimensions.
(2) The bearings at supports are not required.
(3) The view for the traffic below the bridge is the least obstructed in view of the slender dimensions of the supporting piers.

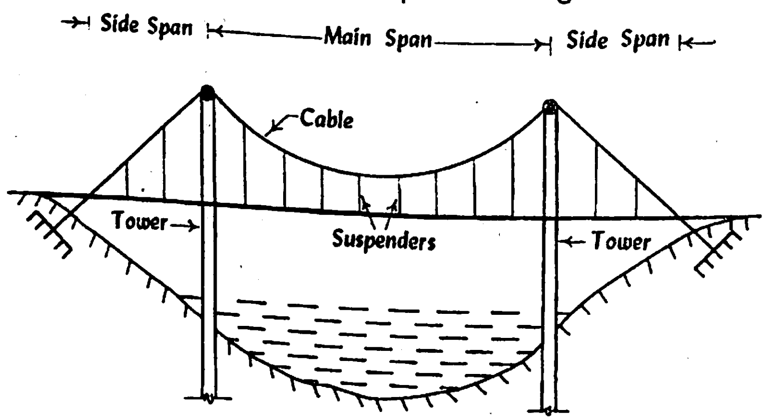
VII. Suspension bridges:

Suspension bridges are ideal solution for bridging gaps in hilly areas because of their simple construction technology and capability of spanning large gaps.

The suspension bridge consists of a hanging cable which is anchored at the *two* ends. The cable takes the shape of a catenary between *two* points of suspension. The flooring of bridge is supported by the cable by virtue of tension developed in its cross–section. The vertical members, known as the *suspenders*, are provided to transfer the load from bridge floor to the suspension cable.

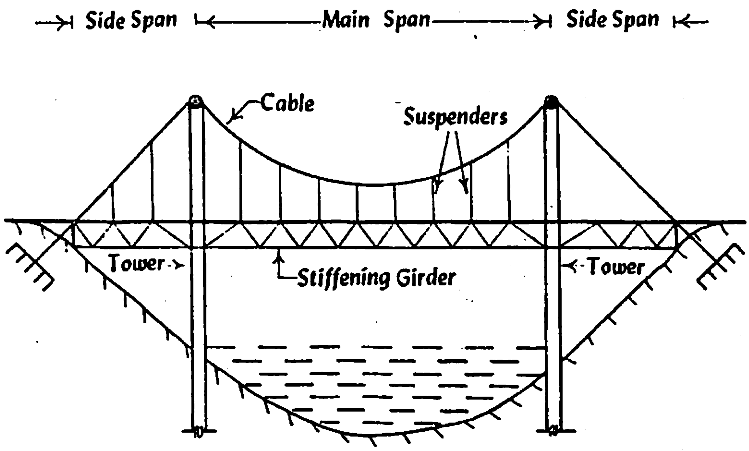
The cables are usually of chains or steel wire ropes. The suspenders are usually of twisted wire ropes and they are connected with the cable by loops. Depending upon the site conditions, the side span to main span ratio varies from 0.17 to 0.50.

The suspension bridges may either be *unstiffened* or *stiffened*. Fig. 4–22 shows an unstiffened suspension bridge. It can be adopted for light traffic and for foot bridges where dead load will be just sufficient to prevent any appreciable change in the shape of bridge.



Unstiffened suspension bridge
FIG. 4–22

Fig. 4–23 shows a stiffened suspension bridge. The stiffening girder assists the cable to become more rigid and to prevent changes in shape and gradient of the roadway platform. It is, therefore, adopted for heavy traffic. The load from the bridge floor is transferred to the stiffening girder and it is conveyed to the cables through the suspenders.



Stiffened suspension bridge
FIG. 4–23

Following are the *advantages* of the suspension bridges:

(1) The construction of piers in bed of river is avoided.
(2) The design is comparatively simple.
(3) They are economical in cost as compared to the cost for other bridges.
(4) They are light in weight.
(5) They can be constructed for long spans exceeding 600 m and can be considered as competitive for spans down to 300 m.
(6) They can be easily and rapidly constructed.
(7) They present better architectural effect.

Following are the *disadvantages* of the suspension bridges:

(1) There are very few suppliers of bridge cables and machined sockets, which are essential parts of a suspension bridge.
(2) Painting is essential for all steel components at regular intervals.

(3) The superstructure cost proves to be higher than other types of spans particularly in span ranges of less than 250 m.

Suspension bridge is one of the earliest technologies known to mankind and it is originated in the Indian sub-continent more than 2000 back. The suspension bridges with longer and longer spans have been developed. In 1816, a suspension bridge with a span of 124 m was built in Philadelphia, U.S.A. and the longest suspension bridge having a span of 1400 m has been constructed in 1982 for the Humber bridge in U.K. As a matter of fact, the suspension bridges can be theoretically constructed for as large a span as 3000 m.

VIII. Cable-stayed bridges:

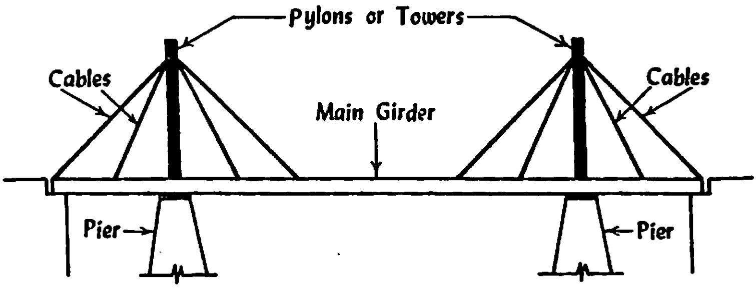
The cable–stayed bridges became popular in France during the earlier part of eighteenth century. However, after the collapse of the Dryburgh–Abbey Bridge, U.K. in 1818 and the Saale River Bridge, Germany in 1824, the French scientist Navier recommended that suspension bridge be built as alternative to cable–stayed bridges. After World War II, the European community reviewed the development of cable–stayed bridge. The first modern cable–stayed bridge was the Stormsund Bridge built in 1955 in Sweden.

The first three major cable–stayed bridges constructed in the United States were the Pasco – Kennewick Bridge built in 1978 across the Columbia River in Washington, the Luling Bridge built in 1983 across the Mississippi River in Louisiana; and the East Huntington Bridge built in 1985 across the Ohio River in West Virginia. At present, about 15 major cable–stayed bridges have been constructed in the United States.

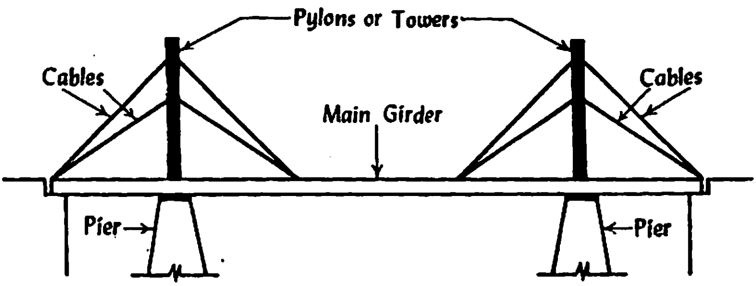
The cable–stayed bridges are similar to the suspension bridges except that there are no suspenders in the cable–stayed bridges and the cables are directly stretched from towers to connect with the decking. Thus, no special external anchorage is required for the cables as in case of the suspension bridges because the anchorage at one end is done in the girder and at the other on top of tower.

Each anchorage in girder introduces horizontal and vertical forces. The cross girders or diaphragms take up the vertical forces. The stiffening girders are designed to take bending stresses and also a compressive force which is induced by the horizontal component of the force in the cable.

Fig. 4–24 and fig. 4–25, show the cable–stayed bridges. The cables can be arranged with *two* plane system or one plane system as shown in fig. 4–24 and fig. 4–25 respectively.



Cable–stayed bridge with two plane system
FIG. 4–24



Cable–stayed bridge with one plane system
FIG. 4–25

The *two* plane system requires additional widths to accommodate the towers and deck anchorages. In case of one plane system, the anchorage at deck level can be accommodated in the traffic median and it results in the least value of the total width of deck. The one plane system is also more aesthetically pleasing because it provides an unobstructed view on one side of the motorist or vehicle driver. On the other hand, a side view of the bridge in the *two* plane system gives the impression of the intersection of the cables.

In principle, the cable–stayed bridge essentially consists of the following *three* elements:

(1) bridge deck,

(2) pylons or towers, and

(3) stay–cables.

The stay–cables are the principal structural elements because they play an important role in the design, stability and performance of the structure as a whole. They can be manufactured in one of the following *three* systems:

(1) locked coil wire ropes or stranded ropes, or
(2) long–lay spiral strand cables, or
(3) parallel or semi–parallel wire cables.

The deck in case of the cable–stayed bridges is supported either by a number of cables meeting in a bunch at the tower, known as the *fan form* or by joining at different levels on the tower, known as the *harp form.* The use of multiple cables facilitates smaller distances between points of supports for the deck girders and it results in the reduced structural depth. The cable–stayed decks are less prone to the wind induced oscillations than the suspension bridges because of the damping effect of the inclined cables.

The bridge deck may be in the form of steel box girders or R.C.C. girders or prestressed concrete girders. The concrete girders possess the following *advantages*:

(1) As their damping effect is very high, the vibration effects are also small.
(2) They possess much higher stiffness and hence, they exhibit comparatively less deflection.

The only drawback in the use of R.C.C. or prestressed concrete bridges is their heavy weight.

The towers may take any form depending on the structural as well as aesthetic considerations and the forms in common use are single column, pair of separate columns, A–frame and portal frame. The slope of the cable affects the height of towers and it is the usual practice to provide additional heights for the towers above the point of connection of the cables for getting better architectural appearance.

The cable–stayed bridges have been found economical for spans upto 300 m. They require light substructures and hence, they are found economical for longer spans. However, due to cantilever effect, their deflection is rather high and hence, they are not preferred for very long spans on the railways.

Following *precautions* should be taken in the construction of the cable–stayed bridges:

(1) *Corrosion protection:* It is necessary to exercise extreme care for the protection of the cables from corrosion. The mere painting will not be sufficient. For this purpose, the cables are placed in tubes which are also tightly connected to the anchorages. The tubes are made of black polythylene and they are found to be good and are expected to need no maintenance for 40 to 50 years, if properly handled during transport, erection and injection.

The other alternative is the use of the stainless steel tubes. Recently, fusion-bonded, epoxy-coated strand has been developed to improve corrosion protection. The first appearance of epoxy-coated strand for a stay cable was in 1986 on the Bayview cable-stayed bridge across the Mississippi River in Illinois. Epoxy-coating is applied to a strand by an electrostatic deposition method.

(2) *Sag of cable:* The use of cables requires their correct design and stressing because the sag of cable under its own weight introduces a complication.

(3) *Voids:* The voids around the wires or strands in the cables must be filled with anti-corrosive material like cement grout by injection after the stressing.

Cementitious grout is commonly used because of its inherent alkalinity, which produces a passive film on the surface. Grouts used for stay cables generally possess good workability and have few air voids which help to retain their volume after placement and have sufficient strength. They also exhibit minimum bleeding, good fluidity and bonding. Water used for grout must be free of harmful substances such as nitrates, sulphides, sulphates and chlorides. Admixtures are generally in liquid or powder form and produce good quality of grout in a short mixture time.

Several different grout materials have been used in the cable-stayed bridges in foreign countries. A petroleum wax blocking compound has been developed and is used in France.

A polybutadiene polyurethane grouting material was used to provide crack-free grout in Japan. Polymer cementitious mortar has also been used on cable-stayed bridges in Japan.

Role of cable sheath in cable-stayed bridge:

The cable sheath has to fulfil the following *three* principal functions:

(i) To serve as a corrosion barrier for the stressing steel in the cable.

(ii) To serve as formwork for injecting grout.

(iii) To contribute to the live load bearing of the cable forces through its longitudinal stiffness.

The following are the *properties* required for a good sheathing material:

(1) Compatibility with the environment.

(2) Low creep characteristics.

(3) Non–reaction with the grout material and steel.

(4) Resistance to damage during shipping, handling, fabricating, installation and grouting.

(5) Resistance to fatigue from cyclic stresses.

(6) Resistance to intrusion of water, gas, etc.

(7) Resistance to ultraviolet degradation.

The following points should be kept in mind for the reliable corrosion protection of cable–stayed bridges:

(1) The stresses to corrosion protection system components during transportation, fabrication and installation may be serious and hence, they must be considered for double corrosion protection.

(2) Durability of the sheathing is critical during the cable service life. Failure of the sheathing can result in corrosion of steel tension elements embedded in cementitious grout. Steel sheathing is protected from corrosion by coating. If corrosion perforates the steel sheathing, the effectiveness of corrosion protection system will be greatly reduced.

(3) It is difficult to install and maintain completely moisture–tight sheathing. The cementitious grout is permeable because it is very thin and it is subject to cracking under dynamic loading. Thus, it offers very limited protection from the outside environment. Hence, new materials which can provide better corrosion protection, should be developed.

(4) The project inspector should be trained properly. He should be familiar with the specifications, inspection techniques, proper installation and crucial problems that can affect the durability of cable-stayed bridge.

The largest suspension bridge of the world, Akashi Kaikyo Bridge spanning the Akashi Straits linking Honshu, the main island of Japan, with the island of Awaji was opened for traffic on April 5, 1998. Salient features of this bridge are given below:

(1) The bridge was designed against 4.1 m/s tidal current, 50 m depth, poor supporting conditions and heavy sea traffic.

(2) The bridge ensures safety against winds of about 80 m/s and earthquake of 8.5 on Richter scale.

(3) The bridge runs across 3934 m strait and total suspended length of the bridge is 3910 m.

(4) Laying down caisson method was used to reduce works on the hard natural conditions encountered on sea. In this method, 80 m dia. circular steel caisson shells were floated and towed to their sites, positioned and held in place with sea–floor anchors before sinking on to previously prepared bearing strata and then pumped full with concrete.

(5) The towers are 288 m high, nearly as tall as the Eiffel Tower of Paris.

(6) The two main parallel–wire cables, having diameter of 1.1 m were erected with prefabricated strand method. A strand consists of 127 high strength galvanized wires which were fabricated in factory and transported to the site to be stretched from one anchorage to another.

(7) About 200000 tonnes of steel have been used for superstructure and 1.42 million cubic metre of concrete for substructure. Everyday, 1990 cubic metre of concrete was poured.

(8) The concrete mix developed and used in this bridge has following specifications:

Low heat cement (clinker 30% slag 70%)	260 kg
Lime stone powder	150 kg
Fine aggregate (sea sand)	615 kg
Coarse aggregate	1137 kg
Water	145 litres
Napthelene based super plasticizer	8.8 litres
Concrete	35 Mpa
Modified alkyl carbonyl oxide	air entrainer.

The concrete was pumped using a six inch pipe at a maximum discharge rate of 68 m^3/hour.

The foundation stone of the proposed cable–stayed bridge across the river Hooghly at Calcutta was laid in 1972. But the actual construction of the bridge started in 1979 due to the difference in opinion between the two foreign consultants, Lua of Germany and Freman Fox and Palmer of the U.K. The construction work was further delayed by technical difficulties in laying one of the foundations about 30 m below the river bottom and also by an accident which damaged a sophisticated pylon erection crane.

This bridge is held by 152 rope wires or cables between four 135 m towering pylons and standing 125 m above the high water level of the river to allow large ships to pass under it. The symmetrical sliding lines of the hanging cables connecting the *two* banks of the river make the bridge both aesthetic and functional. This giant bridge of about Rs. 350 crore is opened for traffic from 10–10–1992 and it is one of the longest cable–stayed bridge with middle span as 457.2 m. The bridge will facilitate the economic development of Howrah which has been languishing under the shadow of city of Calcutta for the last 300 years.

The first cable–stayed road bridge at Hardwar, U.P., was inaugurated on 19–07–1988. The salient features of this bridge are as follows:

(1) The span of the bridge is 130 m. The tower legs have section of 1.10 m × 1.10 m with total height of tower from the bed level as 28.20 m.

(2) The parallel wire cables were manufactured under strictly controlled factory conditions and after coiling on reels, the stay–cables were properly covered with a tarpauline for intermediate storage. The reels were transported to the construction site by the trucks.

(3) The erection at site was done by means of cranes and winches. The cable was lifted at the tower anchorage by means of a crane and guided with the help of a winch installed on the deck and pulleys at the top of tower head to guide the anchor correctly into the bearing plate.

(4) The parallel wire cables were given the triple corrosion protection as follows:

(i) The protection oil was applied on the wires as a temporary measure. This oil does not have any negative influence on the wires.

(ii) The wire cables are enclosed in high density polythylene ducts.

(iii) The final element of corrosion protection was the injection of grout into the pipe. The grout consisted of portland cement of predetermined quality and special additives. After a number of tests performed at site before grouting, the following approved mix design was used for the entire grouting operation:

100 kg cement.
32 litres potable water, and
1 kg admixture.

Materials for superstructures:

Following are the common materials for the construction of various superstructures:

(1) Cement concrete
(2) Masonry
(3) Steel
(4) Timber.

(1) *Cement concrete:* The cement concrete is a popular material for the construction of superstructures. It is usually provided with the reinforcement in suitable directions. The technique of R.C.C. has given the engineer a wide scope of the design for bridges. At present, the pre–stressed cement concrete has come in the field and its adoption results in considerable reduction in sections of various members of the superstructure. In case of pre–stressed concrete bridges, the use is made of high–strength steel generally coupled with high–strength concrete. The pre–stressing of steel and concrete considerably improves the behaviour and strength of a concrete bridge. The pre–stressing of steel enables it to work at a higher stress level and pre–compressing the concrete delays its cracking. The new concepts, techniques and methods have been developed for pre–stressed concrete bridges.

Table 4–1 shows the maximum spans upto which a particular type of cement concrete bridge can be recommended.

TABLE 4-1
CEMENT CONCRETE BRIDGES

No.	Type	Maximum span
1.	R.C.C. arch bridge	200 m
2.	R.C.C. bow-string girder bridge	45 m
3.	R.C.C. cantilever bridges with balanced type construction	30 m
4.	R.C.C. continuous bridge	45 m
5.	R.C.C. deck type girder bridge	20 m
6.	R.C.C. filled spandril fixed arch bridge	35 m
7.	R.C.C. open spandril rib type bridge	60 m
8.	R.C.C. portal frame bridge	15 m
9.	Pre-stressed concrete arch bridge	150 m
10.	Pre-stressed concrete continuous bridge	110 m
11.	Pre-stressed concrete girder bridge simply supported	55 m

For highways, the R.C.C. bridges are found most suitable for small and medium spans and the pre-stressed concrete bridges for long spans. For railways, the R.C.C. bridges are used upto 10 m span and pre-stressed concrete bridges upto 24 m in our country.

(2) ***Masonry:*** The brick masonry or stone masonry is generally used in the construction of arches for bridges of moderate span. The masonry work should be carried out in rich cement mortar. As the masonry is weak in tension, it must be checked that no tension develops in any portion of the arch under the worst combination of dead load and live load.

The bricks to be used for brick masonry should be table-moulded or ground-moulded, well-burnt in kilns, copper-coloured, free from cracks and with sharp and square edges. They should be uniform in shape and should give clear ringing sound when struck with each other. They should be well-soaked in the water before their use.

The stones to be used for stone masonry should be hard, durable and tough and should be of uniform shape. They should be wetted before placed in position. In case of an arch bridge, the stones should be laid or fixed with their natural bedding planes normal to the direction of pressure. This is due to the fact that thrust in an arch is passed from voussoir to voussoir and hence, the natural bedding planes should be parallel to the radiating centre-line of the voussoir.

(3) ***Steel:*** The strength and durability of mild steel have made it suitable for adoption as construction material for superstructures. The steel bridges may either be rolled steel beam bridges or plate girder bridges or trussed bridges.

Table 4–2 shows the maximum spans upto which a particular type of steel bridge can be recommended.

TABLE 4-2
STEEL BRIDGES

No.	Type	Maximum span
1.	Steel arch bridge	500 m
2.	Steel bow–string girder bridge	240 m
3.	Steel cable suspension bridge	1200 m
4.	Steel plate girder bridge	30 m
5.	Steel rolled beam bridge	10 m
6.	Steel truss bridge	180 m

The use of steel bridges for the highways in our country has almost been given up except in the form of composite decks with steel beams and R.C.C. slabs. The other *two* reasons for this change are as follows:

(i) It is difficult to maintain and protect the steel bridges from the environmental effects.

(ii) There is general shortage of steel.

The steel bridges are, however, unavoidable for very long cantilever type of spans and for suspension bridges.

The Indian Railways prefer the steel bridges for spans beyond 25 m because of the following reasons:

(i) The behaviour of steel to the dynamic loads is known with reasonable accuracy.

(ii) They are easy to construct.

(iii) They are light in self–weight.

(4) ***Timber:*** For unimportant bridges and at places where the timber is cheaply available, the timber may be used as material for construction of superstructures. The timber to be used for the bridges should be of the best quality, well–seasoned and free from cracks, knots, flaws, shakes and other defects.

The weakest portion of timber construction is the connections and hence, every effort should be made for the proper detailing of joints of the various members of the timber construction.

The wooden road bridges are classified as the temporary bridges as per I.R.C. Bridge Code and they are to be designed for Class B loading. It is not necessary to consider the impact load in the design of wooden road bridges. The wooden bridges, however, are not suitable for the railways under the present conditions of loading.

The wooden road bridges of span about 64 m are constructed in Canada and U.S.A. But with modern loadings, it is not feasible to adopt the wooden bridges for spans exceeding 45 m. The wooden bridges are not usually recommended on important roads in our country because of their following *disadvantages*:

(i) The connections are to be secured with fastenings of cast–iron or steel.

(ii) The factor of safety for the timber bridges is taken as 4 to 5.

(iii) The life of timber bridges is short because the timber gets easily deteriorated when exposed to the weather agencies like sun, rain and wind.

(iv) The strength of timber is not uniform in all the directions.

(v) The timber components are to be arranged with respect to the direction of load in such a way that excessive stress is not developed in the direction in which the timber is the weakest.

(vi) They are easily liable to fire.

(vii) They cannot be constructed for large spans.

Composite bridges:

Sometimes, a bridge is constructed by a combination of *two* dissimilar materials. Such bridges are known as the *composite bridges* and they are adopted when it is found that a particular material, if used alone, is likely to result in an unusually large section. Under such circumstances, the weak material is strengthened by combining it with another material. The common examples of composite construction are:

(1) concrete beams reinforced with steel bars,

(2) precast pre–stressed concrete girder with cast–in–situ R.C.C. slab,

(3) rolled steel joists topped by a cast–in–situ R.C.C. slab, etc.

Following are the *advantages* of the composite bridges:

(1) It leads to the reduction in deflections and vibrations.
(2) It leads to speed in construction.
(3) It proves to be economical
(4) It results in better quality control.
(6) The cost of foundations for the abutments is reduced.
(7) The cost of transportation is minimized.
(8) The overall depth of beam for a composite construction is reduced and it leads to savings in lengths of approaches.

QUESTIONS

1. Enumerate various types of bridges with the fixed–span superstructures.
2. Describe the various types of simple bridges.
3. What are the advantages of a deck bridge?
4. What are the continuous bridges? Where are they adopted?
5. What are the advantages and disadvantages of the R.C.C. continuous girder bridges over simply supported girder bridges?
6. Describe the cantilever bridges.
7. How are the arches classified?
8. Mention the advantages and disadvantages of the arch bridges.
9. Describe the bow–string girder type bridges.
10. Write short notes on:
    (1) Through bridges
    (2) Filled spandrel arch
    (3) Barrel type arch bridge
    (4) Semi–through bridges
    (5) Bridge with counter–weighted cantilevers
    (6) Continuous bridges
    (7) Cantilever bridges
    (8) Arch bridges
    (9) Cement concrete bridges
    (10) Steel bridges.

11. Enlist the properties required for a good sheathing material in cable–stayed bridges.
12. Which are the points to be kept in mind for the reliable corrosion protection of cable–stayed bridges?
13. Write an explanatory note on the rigid frame bridges.
14. Give sketches of the following:
    (1) Deck bridge
    (2) Open spandrel arch
    (3) Steel bow–string girder bridge
    (4) R.C.C. portal frame
    (5) Suspension bridge
    (6) Semi–through bridge
    (7) Rib type arch bridges.
15. What are the suspension bridges? Mention their advantages.
16. Explain in detail the cable–stayed bridges.
17. Explain the role of cable sheath in cable–stayed bridges.
18. Write a brief note on the materials for construction of superstructures.
19. What are the disadvantages of wooden bridges?
20. Write a critical note on the composite bridges.
21. Differentiate between the following:
    (1) Deck, through and semi–through bridges
    (2) Continuous bridge and cantilever bridge
    (3) Three–hinged arch and fixed arch
    (4) Arch bridge and bow–string girder bridge
    (5) Unstiffened and stiffened suspension bridges
    (6) Filled spandrel arch and open spandrel arch
    (7) Barrel type and rib type arch bridges
    (8) Two plane system and one plane system for cable–stayed bridges.
22. Give reasons for the following:
    (1) A deck bridge is preferred to through bridge for carrying the highway traffic.
    (2) For the same width of bridge, the weight of superstructure in case of a through bridge is more than that of a deck bridge.
    (3) At places where there are chances for foundations to sink or settle, the continuous bridges are not adopted.

(4) If rise to span ratio is above a certain limit, a filled spandrel arch proves to be uneconomical.

(5) The noise, which is very common in case of steel bridges, is almost absent in the arch bridges.

(6) It becomes necessary to provide heavier sections for the abutments and piers of an arch bridge.

(7) In case of a stone arch bridge, the stones should be laid or fixed with their natural bedding planes normal to the direction of pressure.

(8) An open spandrel arch generally proves to be economical.

(9) The supports of bow–string girder type bridges require lighter sections.

(10) A stiffened suspension bridge is adopted for the heavy traffic.

(11) Every effort should be made for the proper detailing of joints of various members of the timber bridge.

(12) It is not possible at present to adopt the wooden bridges for spans exceeding 45 m.

(13) The effect of various horizontal forces such as tractive effort and wind load will be comparatively less on a deck type bridge than that on a through type bridge.

(14) The cantilever bridges are more suitbale for long spans and deep valleys.

(15) The rigid frame bridge gives more stability to the supports as compared to the independent piers of the same dimension.

(16) The masking is required for a three–hinged arch bridge.

(17) The life of timber bridge is short.

(18) No special external anchorage is required for the cables of the cable–stayed bridges.

(19) The stay–cables are the principal structural elements of the cable–stayed bridges.

(20) The use of steel bridges for the highways in our country has almost been given up.

(21) The Indian Railways prefer the steel bridges for spans beyond 25 m.

(22) The cable–stayed decks are less prone to the wind induced oscillations than the suspension bridges.

Chapter 5

MOVABLE–SPAN SUPERSTRUCTURES

General:

In case of bridges with movable–span superstructures, it is so arranged that the superstructure of the bridge does not remain in a fixed position permanently. But it is possible to move the superstructure so as to put the bridge out of use, when necessary. It sometimes so happens that the ships may have to pass through the high level bridges requiring the provision of very high clearance. Such bridges will require very high approaches or highly graded approaches even if the maximum clearance is to be provided in the middle portion only. Where the traffic on the bridge is such that suspension of traffic for a short duration on the road or railway will not materially affect the overall traffic, the high level bridges are built with decks with minimum clearance above H.F.L. for normal passage of water and the middle one or two spans or the entire span will be provided with girders which can be moved for clearing the navigation vessels.

It should be remembered that the movable bridges represent specially designed structures and it is therefore necessary to pay special attention to the machinery involved and the housing, operation and maintenance of such machinery. If an attempt is made to reduce the weight of bridge by using material such as aluminium alloy, the reduction in dead weight of the structure will considerably bring down the cost of power required for the working of the bridge.

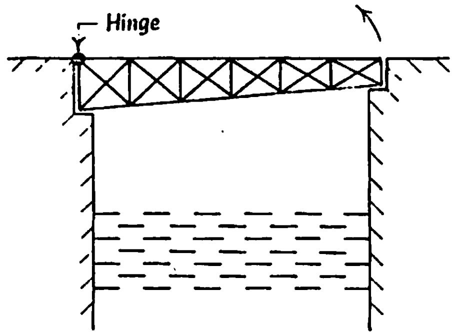
Following are the various bridges with movable–span superstructures:

I. Bascule bridges
II. Cut–boat bridges
III. Flying bridges
IV. Lift bridges
V. Swing bridges
VI. Transporter bridges
VII. Traversing bridges.

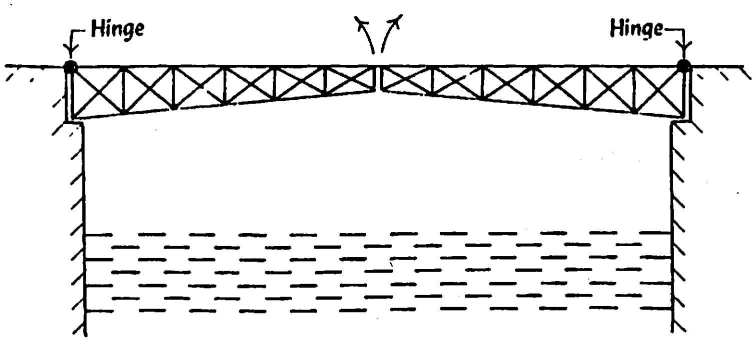
Each of the above type of bridge will now be briefly described in this chapter.

I. Bascule bridges:

In case of a bascule bridge, the entire superstructure is rotated in a vertical plane about a horizontal axis. Suitable rack and pinion arrangement and counter–weights are provided for easy operation of hinge at the bank end of the bascule. An angle of 70° to 80° with the horizontal is formed, when the bridge is in the lifted position.



Single bascule bridge
FIG. 5–1



Double bascule bridge
FIG. 5–2

Depending upon the width of channel, the bascule bridge may either be single or double. Fig. 5–1 shows a single bascule bridge and fig. 5–2 shows a double bascule bridge. It is quite evident that *two* smaller leaves of the double bascule bridge can be raised faster than a single larger one of the single bascule bridge and in addition, the double bascule bridge will require smaller counter–weights and moving parts. The bascule bridge may either be of deck type or through type.

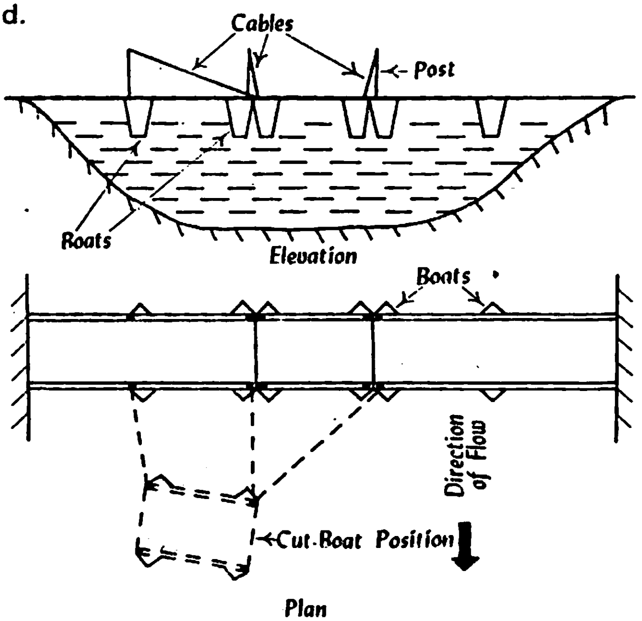
The bascule bridge is generally favoured as it possesses the following *advantages* especially over the swing bridge:

(1) It can be opened easily and rapidly.
(2) It is easy to construct another bascule adjacent to the existing one in future, if need arises.
(3) Its initial cost is low.
(4) The opening can be adjusted in the sense that it can either be made large to allow large vessels or can be made small to allow small vessels.
(5) When it is in the lifted position, the entire span of bridge is available. Hence, the vessels get more space for navigation.

The only drawback of this bridge is that its working is seriously disturbed, when the wind is blowing with high velocity.

II. Cut-boat bridges:

The arrangement of cut-boat bridge is provided for boat bridges i.e. when the superstructure of bridge is resting on the boats. It is so arranged that some portion of the entire span of bridge can be moved on the downstream side with the help of cables attached to adjacent portions as shown in fig. 5-3. This small portion is specially designed and constructed.

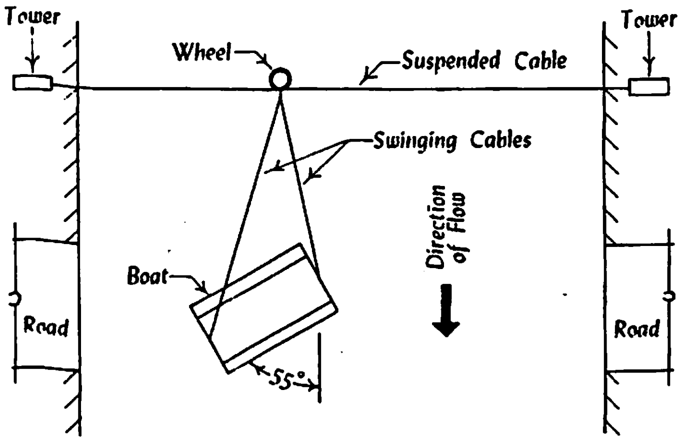


Cut-boat bridge
FIG. 5-3

The cut–boat bridge is provided when it is necessary to provide some passage for the navigation traffic. When the ships pass out, the movable–span is pulled back and it is placed in its normal position.

III. Flying bridges:

In case of flying bridges, a boat or a raft is attached to a suspended cable by means of the swinging cables. It is so arranged that the boat makes an angle of about 55° with the direction of flow. The suspended cable is stretched across the river and it is kept above the level of the highest flood of the stream.



Plan of a flying bridge
FIG. 5–4

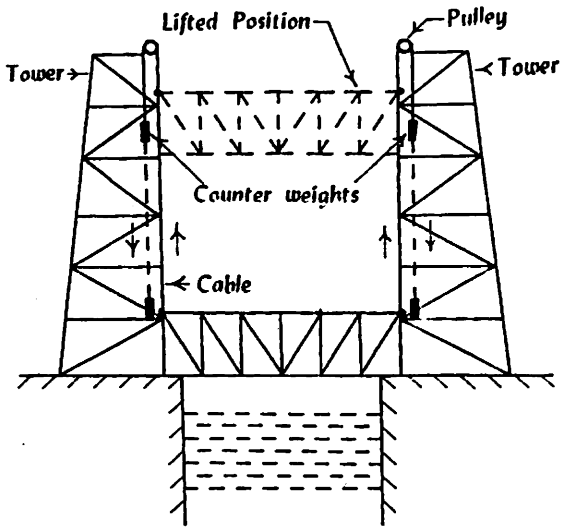
The boat moves from one bank to the other by the pressure exerted by current of flow. When the boat reaches the other end, the direction of swinging cables is changed.

The flying bridges can be used only to carry light passenger traffic. They can be adopted for short spans only and at places where enough materials are not available for the construction of permanent bridge across the stream and the available funds are also too small.

IV. Lift bridges:

In case of lift bridges, the whole span is vertically lifted up by means of suitable arrangement of the pulley and counter–weight as shown in fig. 5–5.

The towers are provided on either side with sheaves or grooves. The rigid trusses of the bridge are moved up and down by the cables which pass over pulleys mounted at the top of the towers and the pulleys in turn are connected to the counter-weights at the other end. When the truss is lifted up in vertical plane, it allows navigation in the channel. A light over-head truss is generally provided at the top connecting the two towers. Such an arrangement results in better bracing and it permits support to a walkway during maintenance work. The lift bridge compares very favourably with the bascule bridge and is found to be cheap in cost for long spans.



Lift bridge
FIG. 5–5

Following points should be noted:

(1) *Number of towers:* The total number of towers may be two or four i.e. one on either side of bank or two on either side of the bank.

(2) *Construction:* The lift bridges are simple to design and construct. It is also easy to operate them.

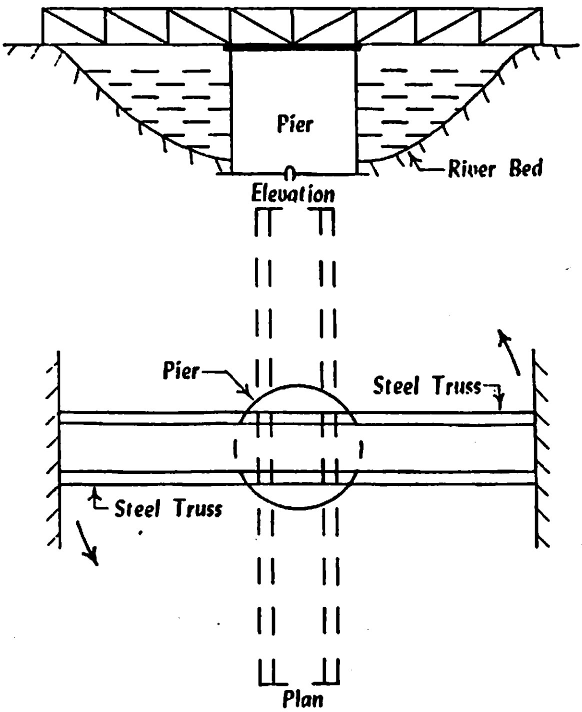
(3) *Overhead trusses:* To give more rigidity to the bridge, the towers may be connected at their tops by the overhead trusses.

(4) *Span:* The span of lift bridge may be equal to the width of stream or river. But if the width of stream or river is more, it may even form the part of total length of the bridge.

(5) *Wind pressure:* The effect of wind pressure on a lift bridge is not appreciable and as such, its working is not seriously disturbed even when the wind is blowing with high velocity.

V. Swing bridges:

In case of swing bridges, a central pier is provided with suitable bearings or rollers. The superstructure consists of a pair of steel trusses and it can be rotated in a horizontal plane about a vertical axis by some suitable equipment. Fig. 5–6 shows plan and elevation of a swing bridge. The dotted lines indicate the position of the bridge after rotation.



Swing bridge
FIG. 5–6

Following points should be noted:

(1) *Flooring:* Depending upon the alignment of road, the flooring of bridge may be placed at the top or bottom boom of the trusses.

(2) *Locking arrangements:* The bridge should be provided with such locking arrangements that it remains parallel to the flow during open position and that it remains in line with road in normal position.

(3) *Position of pier:* It is usually so arranged that the pier divides the length of bridge into *two* equal spans. But if it is not possible to have equal spans, the shorter span

should be provided with necessary extra weight to counterbalance the excess weight of longer span.

The swing bridge is not favoured at present because of its following *disadvantages:*

(1) *Land traffic:* When the swing span is rotated, there is no protection to the land traffic at the water edge.

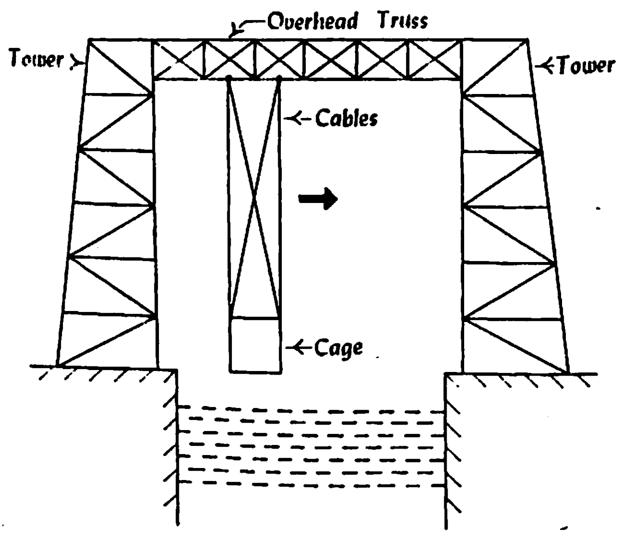
(2) *Navigational capacity:* The bridge divides the wider waterway into *two* narrower halves and hence, the navigational capacity of the waterway is reduced.

(3) *Obstruction to the flow of water:* The pier causes obstruction to the flow of water and it deflects the currents of water towards the banks.

(4) *Time of operation:* The bridge has to be swung for ninety degrees even to allow passage to a small vessel. Thus, it requires a long time for each operation.

VI. Transporter bridges:

In case of transporter bridges, a moving cage is suspended from an overhead truss with the help of cable or wire ropes as shown in fig. 5–7. The overhead truss rests on *two* towers and it contains rails for cage to roll. The cage is loaded with persons or goods and it is then allowed to move from one end to the other end of river. This type of bridge is used within a harbour area to provide an arrangement for shifting of men and materials across a channel.

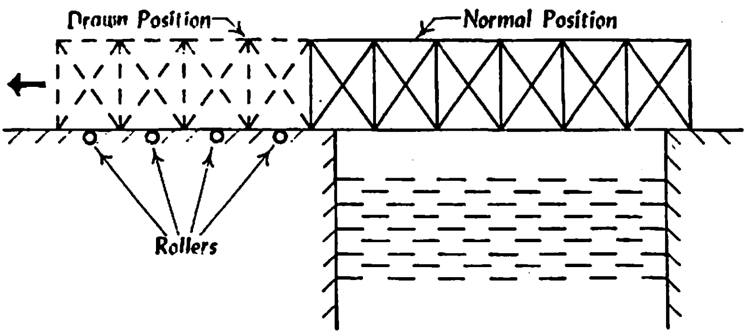


Transporter bridge
FIG. 5–7

The transporter bridge behaves more or less as a ferry than a bridge for the vehicular transport.

VII. Traversing bridges:

In case of traversing bridges, it is so arranged that the whole bridge can fully or partly be rolled forward or backward across the opening as shown in fig. 5–8. The bridge is provided with rollers on the approaches. The traversing bridges are now obsolete.



Traversing bridge
FIG. 5–8

QUESTIONS

1. When are the bridges with movable–span super–structures necessary?
2. Enumerate the various bridges with movable–span superstructures.
3. Describe the bascule bridges and mention their advantages.
4. What are the cut–boat bridges?
5. Write short notes on the following:
   (1) Transporter bridges
   (2) Traversing bridges
   (3) Double bascule bridges
   (4) Lift bridges.
6. Explain the flying bridges.
7. Describe the lift bridges.
8. What are the swing bridges?
9. What are the disadvantages of swing bridges?

10. Give sketches of the following:
    (1) Single bascule bridge
    (2) Cut–boat bridge
    (3) Lift bridge
    (4) Swing bridge.
11. Differentiate between the following:
    (1) Single bascule bridge and double bascule bridge
    (2) Cut–boat bridge and flying bridge
    (3) Lift bridge and swing bridge
    (4) Transporter bridge and traversing bridge.
12. Give reasons for the following:
    (1) The bascule bridge is generally favoured over the swing bridge.
    (2) The working of a lift bridge is not disturbed even when the wind is blowing with high velocity.
    (3) The swing bridge is not favoured at present.
    (4) It is necessary to pay special attention to the machinery involved in the working of the movable bridges.
    (5) A light overhead truss is generally provided at the top connecting the two towers of a lift bridge.

Chapter 6

CULVERTS

Definition:

A *culvert* is defined as a small bridge constructed over a stream which remains dry for most part of the year. A culvert is thus a cross drainage work having a total length not exceeding 6 m between the faces of abutments or extreme ventway boundaries when measured at right angles to the axis of ventway.

The culverts are provided as the cross drainage structures in the following *two* cases:

(1) for draining small pockets or catchments with no definite stream channels and also where the height of the bank is small, and

(2) for small streams with rigid boundaries or semi–rigid boundaries.

According to function or purpose, the culverts may be classified as highway culverts or railway culverts. The design aspects for these *two* classes will be different. The individual cost of each culvert may be small. But in all important highway or railway projects, the total cost of all cross drainage structures in the form of culverts will be substantial.

In this chapter, the topic of culvert will be briefly described.

Waterway of a culvert:

The general principles which are to be observed in the design of the waterway of a culvert can be mentioned as follows:

(1) It should be assumed as flowing only half full when the approach channel is wide and narrow; and can be taken as 3/4 full, if the banks are steep and the channel is narrow.

(2) It should be large enough to carry the flow without any appreciable heading up at the entrance.

(3) It should be placed in such a way that there is adequate cushion above the top of the culvert, specially pipes and arches.

(4) The velocity through the culvert should be limited to 150 cm/sec.

For working out the waterway of a culvert, the following formulas are generally adopted:

(1) *For catchment area upto 40 hectares:*

(i) $A = 0.09\ C$ Suitable for Deccan conditions and permissible velocity of about 3000 mm per second.

(ii) $A = 0.029\ C$ Suitable for North Gujarat conditions and permissible velocity of about 1500 mm per second.

(2) *For catchment area from 40 to 280 hectares:*

(i) $A = 0.05\ C + 1.63$ Suitable for Deccan conditions and permissible velocity of about 3000 mm per second.

(ii) $A = 0.0255 + 1.63$ Suitable for North Gujarat conditions and permissible velocity of about 1500 mm per second.

where A = area of waterway in m^2

C = catchment area in hectares.

Types of culverts:

Following are the *six* different types of culverts:

(1) Arch culverts
(2) Box culverts
(3) Pipe culverts
(4) Slab culverts
(5) Scuppers
(6) Causeways.

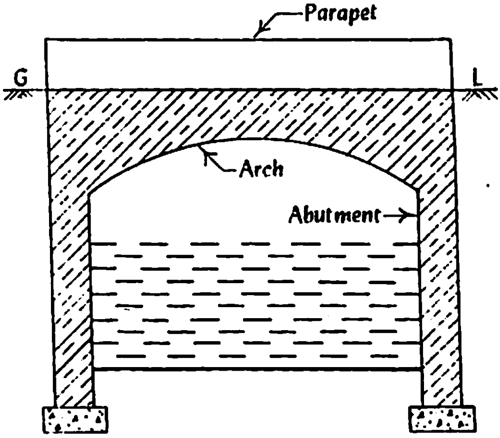
Each of the above type of culverts will now be briefly described.

(1) *Arch culverts:* An arch culvert of stone masonry may be adopted for span ranges of 2 m to 6 m. Fig. 6–1 shows an arch culvert. The arch culvert is provided with the abutments, wing walls and parapet.

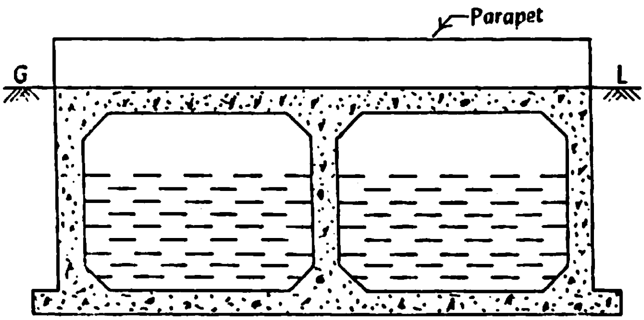
(2) *Box culverts:* In case of box culverts, the rectangular boxes are formed of masonry, R.C.C. or steel. The R.C.C. box culverts are very common and they consist of the following *two* components:

(i) The barrel or box section of sufficient length to accommodate the roadway and the kerbs.

(ii) The wing walls splayed at 45° for retaining the embankments and also for guiding the flow of water into and out of the barrel.



Arch culvert
FIG. 6–1



An R.C.C. box culvert
FIG. 6–2

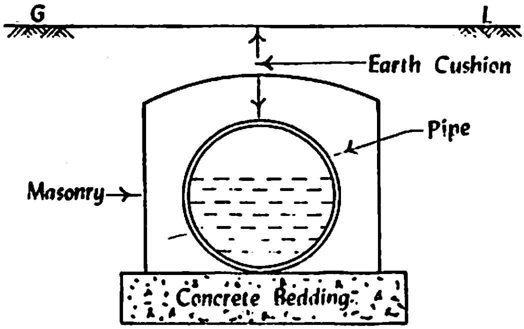
Fig. 6–2 shows an R.C.C. box culvert with *two* openings. Following points should be noted:

(i) *Foundations:* The box culverts prove to be safe where good foundations are easily available.

(ii) *Height:* The clear vent height i.e. the vertical distance between top and bottom of the culvert rarely exceeds 3 metres.

(iii) *Span:* The box culverts are provided singly or in multiple units with individual spans ranging from 1 m to 4 m. When the total span exceeds about 6 m or so, it requires thick sections which will make the construction uneconomical.

(iv) *Top:* Depending upon the site conditions, the top level of box culvert may be at the road level or it can even be at a depth below road level with filling of suitable material.



Pipe culvert
FIG. 6–3

(3) ***Pipe culverts:*** For small streams crossing the road or railway embankments, one or more pipes may be placed to act as the culvert. The diameter of pipe is kept not less than 300 mm. The exact number of pipes and their diameters will depend on the discharge and height of bank. The pipe culvert is useful when there is no defined channel as in case of flat country. Fig. 6–3 shows a typical pipe culvert. The pipes are the cheapest and quickest form of culvert to construct and they are provided when the discharge is low, say upto about 10 m^3/sec.

Following points should be noted while designing pipe culverts:

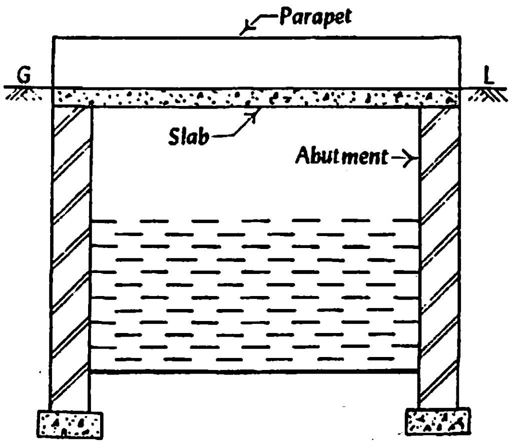
(i) *Concrete bedding:* It is necessary to provide the concrete bedding of suitable depth below the pipes.

(ii) *Construction at ends:* At both ends of pipe culvert, it is preferable to provide masonry head walls with arch at top when the depth of filling is small. The construction of head walls at the ends of the road formation width assists to retain the earth and prevents the stream water to damage the embankment. If the depth of filling is more, it will not be economical to provide high head walls and in such cases, the length of the culvert should be increased in such a way that the embankment, with its natural side slopes, is accommodated without high retaining walls. In both the cases, the splayed wing walls may be provided alongwith the head walls at the ends.

(iii) *Earth cushion:* An earth cushion of minimum depth of 450 mm should be provided at the top of pipes.

(iv) *Material of pipe:* The pipes may be of R.C.C., cast–iron, steel or wood. The cast–iron pipes are suitable upto a diameter of 750 mm and R.C.C. pipes are suitable upto a diameter of 1800 mm.

(4) *Slab culverts:* A slab culvert consists of stone slabs or R.C.C. slab, suitably supported on masonry walls on either side, as shown in fig. 6–4. The slab culverts of simple type are suitable upto a maximum span of 2.50 m or so. However, the R.C.C. culverts of deck slab type can economically be adopted upto spans of about 8 m. However, the thickness of slab and dead weight may sometimes prove to be the limiting factors for deciding the economical span of this type of culverts.

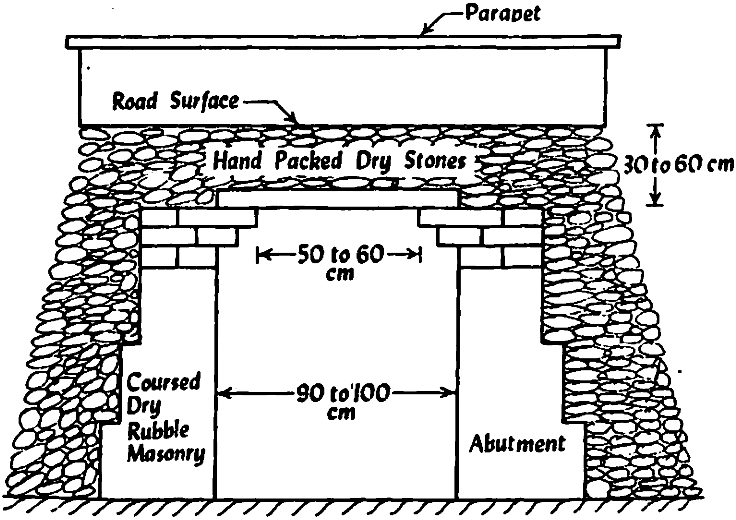


Slab culvert
FIG. 6–4

The construction of slab culverts is relatively simple as the framework can easily be arranged, reinforcement can be suitably placed and concreting can be done easily. This type of culvert can be used for highway as well as railway bridges.

Depending upon the span of culvert and site conditions., the abutments and wing walls of suitable dimensions may be provided. The parapet or hand rail of at least 750 mm height should be provided on the slab to define the width of culvert.

(5) *Scuppers:* A scupper is the cheapest type of culvert and it is provided when the width of stream to be crossed is only about 900 mm to 1000 mm. It is used on unimportant roads. A typical scupper is shown in fig. 6–5. The abutments are constructed with coursed dry rubble masonry and to reduce the width at the top, they are corbelled from both the sides till a gap of 500 mm to 600 mm remains. The gap is then covered up by stone slab or R.C.C. slab. The hand packed dry stones are laid over the slab as well as around the scupper. The retaining walls are constructed on both the ends of the scupper.



Scupper
FIG. 6–5

A scupper is thus a miniature form of causeway and it is often preferred to small culvert in hill sections. It is, however, not suitable for use on the steep gradients.

(6) *Causeways:* The topic of causeways will now be discussed in detail.

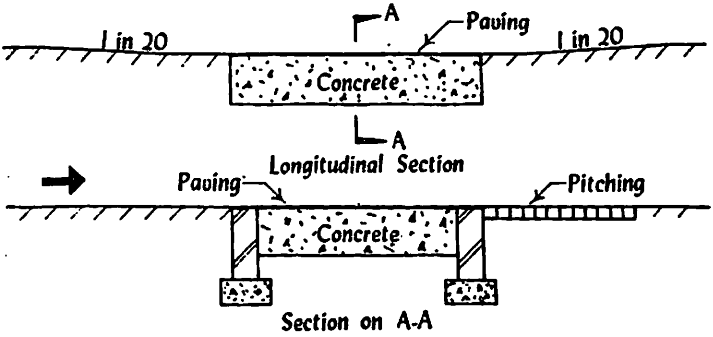
Definition: A causeway is defined as a small submersible bridge at or about the bed level which will allow the floods to pass over it. It is also known as an *Irish causeway* or *dip*.

Types: The causeways are broadly divided into the following *two* categories:

(i) Low level causeway

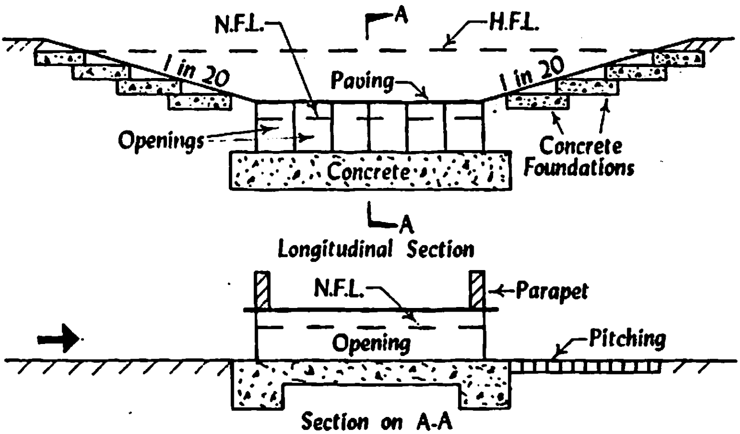
(ii) High level causeway.

The low level causeway or L.L.C. is a small submersible bridge without openings. It is also known as a flush causeway as it is situated at bed level of a stream. Fig. 6–6 shows a low level causeway. If the road surface of the L.L.C. is made simply by spreading the stones only, such a construction is known as the *metal dip* and it is adopted for roads of not much importance.



Low level causeway
FIG. 6–6

The high level causeway or H.L.C. is a small submersible bridge with openings. Fig. 6–7 shows a high level causeway.



High level causeway
FIG. 6–7

Necessity: For most of the small streams which are crossed by roads of secondary importance, the construction of a bridge on the basis of maximum flood discharge is not justified. It is also found for such streams that the high flood is occasional and the normal flow is very little or the bed is dry most of the time. In such cases, it becomes economical to construct a permanent bridge across the stream to take up the average or normal flood discharge.

Thus, the causeways are found to be most suitable where low cost is the main consideration such as village roads, minor district roads, hilly areas, roads sponsored by community projects, etc. It is quite natural that the submersible bridges are not to be adopted for State highways or National highways.

It is quite evident that the whole bridge will be submerged at the time of maximum flood and traffic will, therefore, have to be suspended during the duration of maximum flood discharge. The approaches of the causeway are generally provided with a gradient of 1 in 20 and strong paving is provided at the top surface so that the velocity of water at the time of maximum flood does not dislodge the road. It is also to be seen that the formation level of road on either side of the causeway is higher than the highest flood level or H.F.L.

Conditions to be satisfied: Following conditions, if satisfied, justify the construction of a causeway across the steam:

(i) Depth of water: The seasonal flow of water in the stream should not be more and the depth of water should be very small.

(ii) Highest flood discharge: It is essential to check that the highest flood discharge does not flow in the stream for more than 8 to 10 days in a year and also for about 4 to 5 hours continuously during these days. It should also be seen that the stoppage of traffic due to the passage of high floods is not likely to exceed 3 days at a time and not more than 18 days during the course of the year.

(iii) Normal flood discharge: The normal or average flood discharge of the stream should not be more than 40 per cent of the highest flood discharge.

Data to be collected: Following data should be collected before the project of causeway is taken in hand:

(i) availability of fund,

(ii) flood statistics of the stream for 10 to 12 years,

(iii) importance of road,

(iv) nature of traffic, etc.

Design of H.L.C.: Following procedure is adopted in the design of H.L.C.:

(i) The cross-section of the stream is drawn.

(ii) The normal flood discharge is marked on the cross-section and area of waterway upto normal flood level is worked out.

(iii) From the cross-section, the wetted perimeter upto normal flood level is calculated.

(iv) The slope of bed of stream at the site of causeway is determined.

(v) From the above details, the velocity of flow at the site of causeway is calculated.

(vi) The suitable section of causeway is assumed according to the tentative arrangement of the openings.

(vii) If the normal flood level is accommodated in the openings with suitable clearance, the assumed section is adopted. Otherwise, suitable adjustments are made in the assumed section of the causeway.

(viii) The H.F.L. is plotted on the cross–section of cause–way. The strong concrete foundations should be provided on the approaches upto the H.F.L.

QUESTIONS

1. Define a culvert and where are they provided?
2. What are the general principles to be observed in the design of the waterway of a culvert?
3. State how the waterway of a culvert is worked out.
4. Write short notes on:
   (1) Arch culverts
   (2) Pipe culverts
   (3) Slab culverts
   (4) Scuppers.
5. Describe the box culverts.
6. Define a causeway and describe its types.
7. What is the necessity of providing a causeway?
8. State the conditions to be satisfied and data to be collected for a causeway.
9. Describe the procedure of design of H.L.C.
10. Give sketches of the following:
    (1) R.C.C. box culvert
    (2) Pipe culvert
    (3) Scupper
    (4) Low level causeway
    (5) High level causeway.

11. Differentiate between the following:
    (1) Minor bridge, major bridge and long span bridge
    (2) Arch culvert and box culvert
    (3) Pipe culvert and slab culvert
    (4) Low level causeway and high level causeway
    (5) Flush causeway and metal dip.
12. Give reasons for the following:
    (1) The construction of slab culverts is relatively simple.
    (2) The causeways are found to be most suitable where low cost is the main consideration.
    (3) The approaches of the causeway are provided with strong paving.
    (4) If the span of box culvert exceeds 6 m, its construction proves to be uneconomical.
    (5) At both ends of pipe culvert, it is preferable to provide masonry head walls with arch at top when the depth of filling is small.

Chapter 7

FLOORING

General:

The top surface of bridge floor is covered up with suitable flooring material. In this chapter, the various flooring materials suitable for bridge floors will be discussed.

Factors affecting the choice of flooring material:

Following factors should be carefully considered while deciding the type of flooring material for the bridge:

(1) availability of local materials and labour,
(2) climatic conditions,
(3) fund available for flooring,
(4) importance of the bridge,
(5) intensity of traffic,
(6) nature of the bridge,
(7) nature of traffic, and
(8) use of the bridge.

Requirements of a good flooring material:

Following are the requirements of a good flooring material for a bridge:

(1) It should be able to absorb the vibrations and impact caused by the traffic.
(2) It should be capable of being easily drained.
(3) It should be cheap in construction as well as in maintenance.
(4) It should be fire–proof.
(5) It should be non–absorbent, dust–proof and non–slippery during monsoon.
(6) It should be strong and durable.
(7) It should grant a sense of safety to the bridge users.
(8) It should not create noise when traffic passes over it.
(9) It should not give glare to the traffic.
(10) It should provide a smooth riding surface for the traffic.

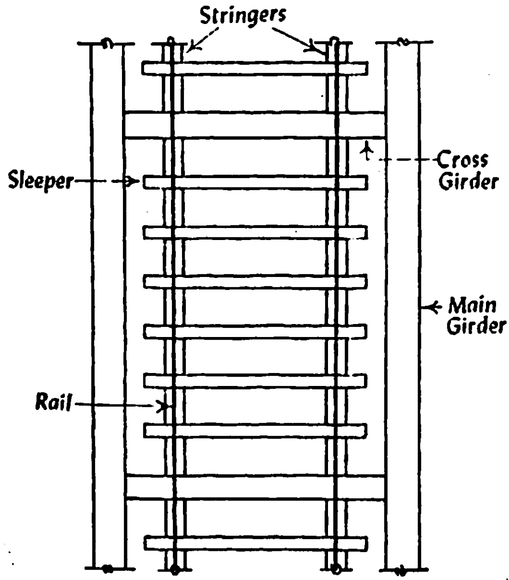
Types of floors:

The bridge floors may broadly be divided into the following *two* categories:

(1) Open floors
(2) Solid floors.

Each of the above type of bridge floor will now be described in brief.

(1) *Open floors:* In case of open floors, the space between the main girders is covered by the required parts of floor only and the remaining space, as such, is kept open. Hence, no flooring material will be required for such floors and as such, the open floors will not require any drainage provisions.



Open floor
FIG. 7–1

The open floors are adopted for the railway bridges which are situated outside the limits of town or city. Fig. 7–1 shows the plan of a typical open floor for a single track railway bridge. The open floors can be easily inspected and they prove to be economical.

(2) *Solid floors:* In case of solid floors, the top surface of the floor of highway bridge or railway bridge is covered up by a suitable flooring material.

Flooring materials:

Following are the common flooring materials which are adopted for the solid floors:

(1) Jack arch

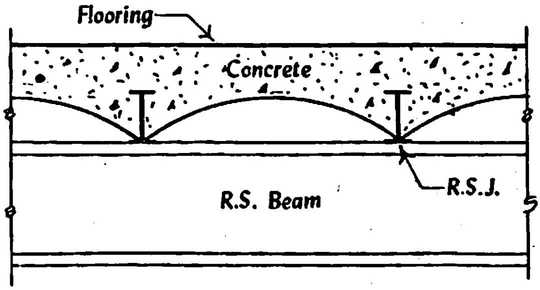
(2) Mild steel buckle plates

(3) Mild steel plates

(4) Mild steel troughs
(5) Reinforced cement concrete
(6) Timber.

Each of the above type of flooring material will now be briefly described.

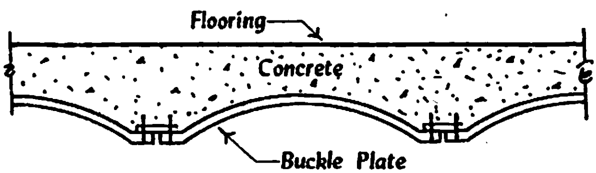
(1) *Jack arch:* In this type of floor, the cement concrete arches are constructed and these arches rest on the lower flanges of mild steel joists as shown in fig. 7–2. The joists in turn rest on R.S. beam.



Jack arch floor
FIG. 7–2

The joists are placed at a distance of about 800 mm to 1200 mm centre to centre. The rise of arch should be 100 mm to 200 mm and the minimum depth of concrete at the crown should be 150 mm. A suitable elastic material is provided at the top of arches to absorb the shocks due to impact.

(2) *Mild steel buckle plates:* The mild steel buckle plates are bent in the form of an arch and they are available in the standard sizes. The thickness of buckle plates varies from 6 mm to 11 mm and the rise is about 60 mm to 90 mm. The space above the buckle plates is filled up by the asphalt or concrete. The minimum depth of filling at the crown should be 75 mm. The buckle plates are connected as shown in fig. 7–3.



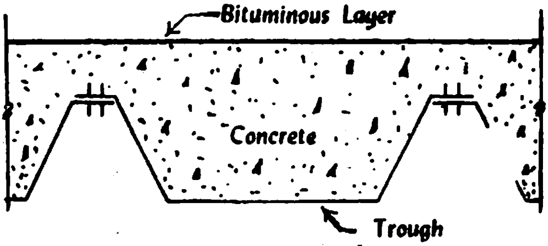
Buckle plate floor
FIG. 7–3

The buckle plates may be fixed either between the main girders or between the cross–girders. If they are fixed between the main girders, the cross–girders and stringers will not be required. If they are fixed between the cross–girders, only the stringers will be eliminated.

The buckle plates flooring is very common for the highway bridges.

(3) *Mild steel plates:* In this case, the flat mild steel plates of thickness about 15 mm, are provided to act as flooring material for the bridge. The steel plates are suitably supported and enough holes are provided to drain off the rain water.

(4) *Mild steel troughs:* A trough is a steel section prepared in a particular shape as shown in fig. 7–4. The trough floor is similar to the buckle plate floor except that the troughs are used in place of the buckle plates. The troughs are usually filled up with concrete with a depth of about 75 mm above the top of trough. A bituminous layer is provided over the concrete.



Trough floor
FIG. 7–4

The troughs may be fixed transversely or longitudinally as in case of the buckle plates. In the first case, the troughs are fixed between the main girders and it results in the elimination of cross–girders and stringers. In the second case, the troughs are placed longitudinally across the cross–girders and it results in the elimination of stringers.

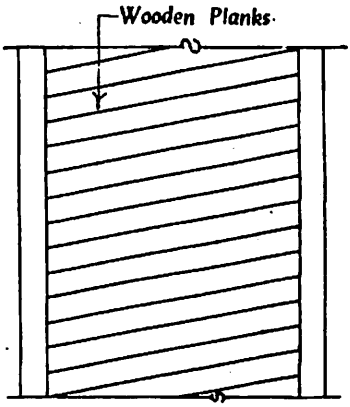
The trough flooring is used for road bridges or railway bridges. If it is to be adopted for a road bridge, a wearing coat is provided over the bituminous layer. If it is to be adopted for a railway bridge, the ballast is spread over the bituminous layer. Alternatively, the sleepers may directly be placed over the troughs and the troughs may be filled up with the ballast instead of the concrete.

(5) ***Reinforced cement concrete:*** In case of R.C.C. floor, a slab of suitable thickness is provided with necessary reinforcement. The R.C.C. flooring is not adopted for the railway bridges. But it has become very popular for the highway bridges.

(6) ***Timber:*** In case of the timber flooring, the wooden planks of suitble thickness are used. However, they are liable to catch fire. The wooden floor is light in the weight as compared to the floors of other materials. The wooden floor is suitable for the foot–overs only to carry the light traffic.

Following points should be noted in connection with the timber flooring:

(i) *Arrangement:* The wooden planks are placed slightly in an inclined position as shown in fig. 7–5.



Timber floor
FIG. 7–5

(ii) *Layers:* The wooden planks may be placed either in single layer or double layer. For single layer, the minimum thickness is 75 mm. For double layer arrangement, the minimum thicknesses of upper and lower layers should respectively be 40 mm and 75 mm.

(iii) *Life:* If wood of superior quality is used and if wooden planks are well maintained, the timber flooring is quite durable and it can have a useful life of 5 to 10 years. However, they are liable to catch fire.

(iv) *Weight:* The timber flooring is light in weight as compared to other flooring materials.

Drainage of floors:

The bridge floors should be given necessary slope in the transverse direction and the holes or space should be kept at the edges to drain off the water. If this precaution is not taken, the water collected over the bridge floor may cause inconvenience and discomfort to the bridge users.

QUESTIONS

1. Mention the factors which affect the choice of flooring material.
2. What are the requirements of a good flooring material?
3. What are the two types of bridge floors?
4. Describe the use of following materials as the flooring materials for the bridges:
   (1) Jack arch
   (2) R.C.C.
   (3) Timber.
5. Discuss the use of mild steel buckle plates, plates and troughs as flooring materials for the bridges.
6. Write short notes on:
   (1) Drainage of bridge floors
   (2) Open floors
   (3) Flooring of mild steel troughs
   (4) Timber flooring.
7. Differentiate between the following:
   (1) Open floor and solid floor
   (2) Mild steel buckle and mild steel trough
   (3) Jack arch floor and R.C.C. floor.
8. Give reasons for the following:
   (1) The open floors will not require any drainage provisions.
   (2) The open floors are adopted for the railway bridges.
   (3) The timber flooring is used for the light traffic only.
   (4) Suitable arrangement is made to drain off the water for the solid floors.
   (5) A suitable elastic material is provided at the top of jack arch floor.

Chapter 8

LOADING ON BRIDGES

General:

A bridge is to be designed for the worst effects produced by various forces, loads and stresses which are acting on it simultaneously. The loads on the bridges are partly imposed by the vehicle and the user and partly by nature. It was found necessary to lay the standards for the guidance of the engineers to design the bridge structure so that uniformity is maintained in designing the same.

In 1903, the Swiss Institute of Engineers and Architects introduced for the first time the provisional standard specifications for the bridges. It was followed in 1910 by Austria, France and Germany. The standards have now been laid down all over the world both by the railways and highway departments.

The public roads and railways in India are managed and controlled by the Government and hence, the bridges to be constructed for roads and railways are to be designed as per standards set up by the concerned authorities. For highway bridges, the standard specifications are contained in the Indian Roads Congress (I.R.C.) Bridge Code and for railway bridges, the Indian Railway Standard (I.R.S.). Bridge Rules are framed to accommodate the standard specifications. The Bureau of Indian Standards (BIS) has also framed specifications for certain types and conditions of bridges and they are to be followed, whenever applicable.

To facilitate easy working, the Indian Roads Congress has issued printed booklets containing drawings for slabs and beams for standard spans and also for piers and abutments of normal heights. Similarly, the Research Design and Standards Organisation (RDSO) of the Indian Railways has evolved drawings for standard spans and also computer programmes for the design of piers and abutments. The detailed design is therefore carried out only in respect of the bridges with long spans and having very deep waterways.

It may be mentioned that the structural design of a bridge is a subject by itself and the only thing intended to cover up in this chapter is to mention the broad outline of loading on the bridges.

Following are the various such forces, loads and stresses acting on a bridge:

I. Buoyancy pressure
II. Centrifugal forces
III. Dead load
IV. Deformation stresses
V. Earth pressure
VI. Erection stresses
VII. Impact load
VIII. Live load
IX. Longitudinal forces
X. Secondary stresses
XI. Seismic load
XII. Temperature variation forces
XIII. Water pressure
XIV. Wind load.

It may be mentioned that none of the forces mentioned above, except the dead load and the live loads in the static state, can be precisely estimated and hence, the empirical or semi–empirical methods have been evolved for working out these forces. Such formulas are generally based on experience and to a certain extent, on the observations made on the models.

Each of the above force, load or stress will now be briefly described.

I. Buoyancy pressure:

The effect of buoyancy is considered in the design of bridge, only if the strata of soil are permeable or in other words, if the bridge foundations are resting on homogeneous and impermeable strata of soil, on provision is made for buoyancy in the design of bridge. The important facts to be remembered while considering the force of buoyancy are as follows:

(1) The effects of buoyancy are to be considered in the design of an abutment, especially the abutments of a submersible bridge. In such a case, it is assumed that the filling behind the abutment is washed away or removed by the scouring action.

(2) For the design of submerged masonry or concrete structure the buoyancy effect through pores is limited to the extent of 15 per cent of the full buoyancy effect.

(3) For the design of submersible bridges, the full buoyancy effect on the superstructure, piers and abutments is to be considered.

(4) If member under consideration displaces water only, the reduction in weight due to the buoyancy for that member is taken as equal to the volume of the displaced water.

(5) If member under consideration displaces silt or sand in addition to water, the reduction in weight due to buoyancy for that member is worked out by taking into account the *two* factors, namely, (a) upward pressure due to the submerged weight of silt or sand and (b) full hydrostatic pressure due to a depth of water equal to the difference in levels between foundation of member under consideration and free surface of water. For finding out upward pressure due to the submerged weight of silt or sand, the Rankine's theory is applied by assuming suitable angle of internal friction. In case of (b), the free surface of water is worked out for the worst condition.

II. Centrifugal forces:

When a road or a railway bridge is situated on a curve, the effect due to centrifugal force is to be considered in the bridge design. Following formulas are adopted for the road and railway bridges:

(1) *Road bridges:*

$$C = \frac{WV^2}{12.95\,R}$$

where C = Centrifugal force in kilonewtons acting normally at the point of action of the wheel loads or in kilonewtons per m length in case of uniformly distributed live load

W = Live load in kilonewtons in case of wheel loads or in kilonewtons per m length for uniformly distributed live load

V = Designed vehicle speed in km p.h.

R = Radius of curvature in m.

The horizontal load due to centrifugal force is considered to be acting at a height of 1200 mm above the level of the carriageway and it is not to be increased for the impact effect.

(2) *Railway bridges:*

$$C = \frac{WV^2}{12.95\,R}$$

where C = Horizontal load due to centrifugal force in kilonewtons per m length

W = Equivalent uniformly distributed load in kilonewtons per m length

V = Maximum speed in km p.h.

R = Radius of curvature in m.

The horizontal load due to centrifugal force is considered to be acting at a height of 1830 mm above the rail level for B.G. and at a height of 1450 mm above the rail level for M.G.

The expression for both types of bridge in m.k.s. system will be as follows:

$$C = \frac{WV^2}{127\ R}$$

where C and W will be taken in tonnes instead of kilonewtons.

III. Dead load:

The dead load indicates the load of structure itself. It depends on various factors such as live load to be carried, length of span, working stresses adopted in the design, etc. It has to be initially assumed for the design purpose. Following *two* rules are followed:

(1) The dead load of the structure is assumed by reference to suitable empirical formulas or by comparison to similar existing structure.

(2) After the design is finalized, the actual weight of structure is worked out. If there is appreciable difference between the actual and assumed dead loads, the design is revised accordingly.

Some of the important empirical formulas adopted for various structures are as follows:

(1) Unwin's formula:

$$W = \frac{PLr}{2cf - Lr}$$

where W = Weight of one span in tonnes excluding weight or cross–girders and flooring

P = Load to be carried in tonnes

L = Span in m

r = Ratio of span to depth

f = Working stress in tonnes per cm^2

c = Constant which varies from 1200 to 1400 for plate girders and from 1700 to 1900 for trusses.

(2) *American formula for plate girders:*

$$W = \frac{P\ L}{2.4\ d}$$

where W = Weight of plate girder in kg

P = Total live load carried in kg

L = Span in m

d = Total depth of girder in cm.

(3) American formula for trusses:

$$W = 0.3\ P + 25\ b + \frac{b - 1.83}{1.62} + \frac{L^2}{20}$$

where W = Weight in kg per m excluding weight of cross-girders and flooring

P = Live load in kg per m^2

b = Clear width of roadway in m

L = Span in m.

(4) *R.C.C. arches:*

$$W = 16.4\ C\ L$$

where W = Average dead load in kg per m^2, including weight of the wearing surface and weight of fill above the crown

L = Span in m

C = Constant. It depends on the ratio of rise to span of the arch. Its values for rise to span ratios of $\frac{1}{4}$, $\frac{1}{5}$ and $\frac{1}{6}$ are respectively 12.40, 10.40 and 9.00.

(5) *R.C.C. slab bridges upto 6 m span:*

$$W = 425 + 148\ L$$

where W = Dead load in kg per m^2 including load of wearing surface of 195 kg per m^2

L = Span in m.

(6) *R.C.C. slab and T beam bridges:*

$$W = 425 + 82\ L$$

where W and L are as above. This formula is adopted for spans from 6 m to 15 m.

IV. Deformation stresses:

Any bending stress which is developed in a steel member either due to vertical deflection or rigidity of the joints is termed as the *deformation stress*. The deformation stresses are to be taken into consideration for steel bridges only. The steel bridges are to be designed, manufactured and erected in such a way that the deformation stresses are brought down to a minimum possible level. For the purpose of assumption only, the deformation stresses may be taken as not less than 16 per cent of the live load and dead load stresses. The deformation stresses are to be ignored in case of prestressed girders of steel.

V. Earth pressure:

The components of bridge which are required to retain earth should be designed for suitable earth pressure. The position of live load on earth causes pressure which is known as the *live load surcharge* and it should be properly considered in the design of bridge.

The I.R.C. recommends the theory of Coulomb with a slight modification. The height of the centre of pressure above bottom is to be taken as 0.42 of the height of wall above the base instead of 0.33 of that height as per Coulomb's theory. It should also be seen that a bridge structure is designed for a minimum horizontal pressure equivalent to the one exerted by a fluid weighing 4800 N per m^3.

The design of abutments of the railway bridges is based on the Rankine's principles. The use of Rankine's theory may be considered conservative. But the Indian Railways have adopted this theory considering the vital nature of the bridge structures.

VI. Erection stresses:

When the structure is being erected, some stress is likely to occur in its various members. The stress so developed in the member may be of different type than the one which develops during the normal use of the member. The erection stress should be checked and if it is not within the permissible limit, adequate provision should be made in the design for offering resistance to it.

VII. Impact load:

The stresses developed due to fast moving heavy vehicles over uneven surfaces in case of road bridges or due to trains moving over uneven rails in case of railway bridges are known as the *stresses due to impact*.

Following points should be noted in connection with the impact load:

(1) *Depth of floor:* If the depth of solid floor of bridge is more, the effect of impact is less.

(2) *Filling of arch:* In case of spandrel–filled arch bridges, the effect of impact is considerably reduced due to absorbing power of filling.

(3) *Footways:* The footways are not designed for the impact load.

(4) *Hammer blow action:* In case of road bridges, the hammer blow action is absent. Hence, the impact effect due to hammer blow action is more prominent in case of the railway bridges than in case of the road bridges.

(5) *Span:* The impact load is inversely proportional to the span. It is, therefore, smaller on a large span than on a short span.

(6) *Speed of vehicle:* The impact load, within certain limits, increases with the increase in speed of the vehicle.

The provision made in the design of a bridge for impact is expressed as a fraction of the live load stress. Such a fraction is termed as the *impact factor or coefficient of impact*. The analytical method of finding out the impact factor is very complex. The various empirical formulas are, therefore, framed to work out impact factor and it is observed that results obtained by the application of these formulas are fairly accurate.

Following are the commonly used empirical formulas for the impact factor:

For road bridges:

(1) *Road organization of Great Britain:*

$$I = \frac{80}{90 + 1.64L\,(n + 1)}$$

where I = Impact factor, subject to a maximum of 0.70

L = Span in m

n = Number of traffic lanes.

(2) *Indian Roads Congress:*

(i) *For I.R.C. Class A or B loading:*

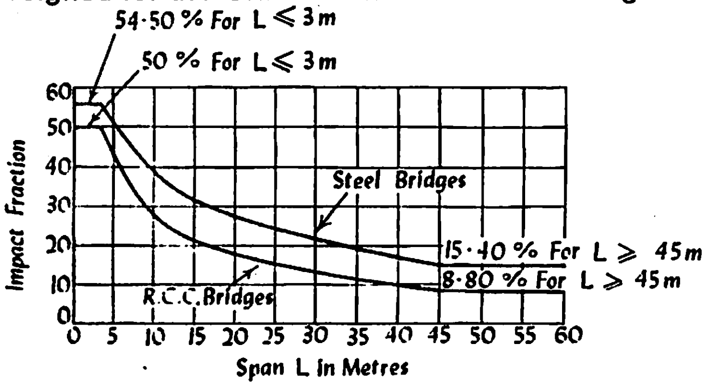
$$I = \frac{4.5}{6 + L} \quad \left(\text{for R.C.C. bridges of spans less than 3 m with a maximum value of 0.50}\right)$$

$$I = \frac{9}{13.5 + L} \quad \left(\text{for steel bridges of spans less than 3 m with a maximum value of 0.545}\right)$$

where I = Impact factor

L = Span in m.

When the span exceeds 45 m, the impact factors for R.C.C. bridges and steel bridges are taken respectively as 0.088 and 0.154. The curves as shown in fig. 8–1 may be used to determine the impact percentages for the highway bridges designed for the Class *A* and Class *B* loading of I.R.C.



Curves showing impact percentages for R.C.C. and steel bridges

FIG. 8–1

(ii) *For I.R.C. Class AA loading:*

Table 8–1 shows the impact factors for I.R.C. Class *AA* loading.

Following points are to be noted in connection with the impact factors for the I.R.C. loadings:

(i) The impact allowance should be made for the design of bearings.

(ii) The substructure is designed partly for impact load and depending upon the depth, a reduction factor is applied to the impact factor as shown below:

Bottom of bed block	..	0.50
For the top 3 m of the substructure below the bed block Zero	..	0.50 decreasing uniformly to zero
For portion of substru–cture more than 3 m below the bed block	..	0.00

(iii) If there is filling of any material including road crust of depth not less than 600 mm, the allowance for impact may be reduced to one–half as worked out from above considerations.

(iv) The span covered by the load should be taken as the effective span length.

TABLE 8–1
IMPACT FACTORS FOR I.R.C. CLASS *AA* LOADING

Description	Tracked vehicles	Wheeled vehicles
(a) Main girders having effective spans greater than 9 m:		
R.C.C. bridges	0.10 upto 40 m span and 0.088 upto and above 45 m span	0.25 for spans upto 12 m; varying from 0.25 to 0.088 for spans between 12 m and 45 m; and 0.088 for spans greater than 45 m.
Steel bridges	0.10 for all spans	0.25 for spans upto 23 m; varying from 0.25 to 0.154 for spans between 23 m and 45 m; and 0.154 for spans greater than 45 m.
(b) Floor system and main girders having effective spans less than 9 m:		
R.C.C. bridges or steel bridges	0.25 for spans upto 5 m linearly reducing to 0.10 for spans of 9 m.	0.25

For railway bridges:

(1) *Railway organization of Great Britain:*

$$I = \frac{120}{90 + 1.64L(n+1)}$$

where I = Impact factor
L = Span in m
n = Number of tracks.

(2) *Waddell's formulas:*

$$I = \frac{165}{3.28\ n\ L + 150}$$

where I = Impact factor
L = Span in m
n = Number of tracks.

For electric railways, with 'n' number of tracks, the formula is as follows:

$$I = \frac{120}{3.28\ n\ L + 175}$$

(3) *Indian Railway Board:*

The Indian Railways treat this as dynamic augment and it is taken as an addition to the live load equivalent to the coefficient of dynamic augment (CDA) or impact factor I multiplied by the live load which gives the maximum bending or shear force in the member under consideration. The value of I specified now is based on the extensive tests carried out by the Indian Railways and it is applicable for speeds upto 160 km p.h. on B.G. and 100 km p.h. on M.G.

Let $$i = 0.15 + \frac{8}{(6 + L)}$$

where L = Loaded length of span in m for the position of the train giving maximum stresses in the member under consideration.

Then, $$I = x \times i$$

where I = Impact factor or coefficient of dynamic augment (CDA)

x = Multiple whose values are given in table 8–2.

For narrow gauge track,

$$I = \frac{91.5}{91.5 + L}$$

where I and L are as above.

TABLE 8–2
IMPACT FACTORS—I.R.B.

Gauge	Description	Value of x	Maximum value of I
Broad gauge and metre gauge	Single track	1.00	1.00
	Main girders of double track spans with two girders	0.72	0.72
	Intermediate main girders of multiple track spans	0.60	0.60
	Cross–girders carrying two or more tracks	0.72	0.72

For foot bridges, no allowance is made for the impact. For railway pipe culverts, arched bridges, R.C.C. culverts, slabs and girders for all gauges, the provision for impact is made as follows:

(i) *For depth of fill more than 900 mm:*

$$I = 0.50 \times \left(0.15 + \frac{8}{(6+L)}\right),$$ subject to a maximum of 0.50.

The depth of fill is the distance from the underside of the sleeper to the crown of an arch or the top of a slab or a pipe. When the depth of fill exceeds 900 mm, the impact factor should be uniformly decreased to zero within the next 3000 mm of fill.

(ii) *For depth of fill less than 900 mm:*

$$I = \left(2 - \frac{d}{0.90}\right) \times 0.50 \times \left(0.15 + \frac{8}{(6+L)}\right)$$

where d = depth of fill in m.

The impact factors for (i) and (ii) conditions mentioned above are applicable to both single and multiple track bridges. For multiple track arch bridges exceeding 15 m in span, only two–third impact factor is to be considered.

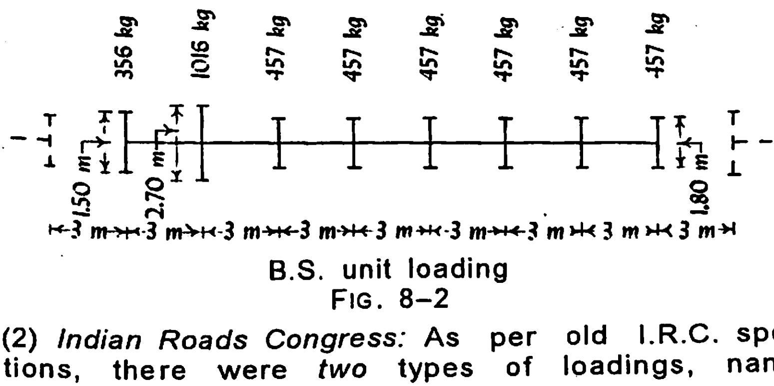
VIII. Live load:

It is evident that maximum live load will depend on the situation of structural member under consideration. In practice, the standard loadings are framed for convenience in the design of bridges.

Following are such standard loadings:

For road bridges:

(1) *British Standard or B.S. unit loading:* Fig. 8–2 shows the unit loading that is adopted as per B.S. specifications. The minimum number of units recommended to be taken in the design of all the bridges is 15.



B.S. unit loading
FIG. 8–2

(2) *Indian Roads Congress:* As per old I.R.C. speci–fications, there were *two* types of loadings, namely standard loading and heavy loading.

Standard loading: As per standard loading, a load of 1.13 t per m length of each traffic lane plus a concentrated load of 6.10 t were taken for determining the maximum B.M. The minimum value recommended to be adopted for spans upto 6 m was 6.78 t.

Heavy loading: As per heavy loading, a load of 1.93 t per m length of each traffic lane plus a concentrated load of 7.10 t for computing B.M. for 10.16 t for computing S.F., were taken. The minimum value recommended to be adopted for spans upto 6 m was 11.58 t.

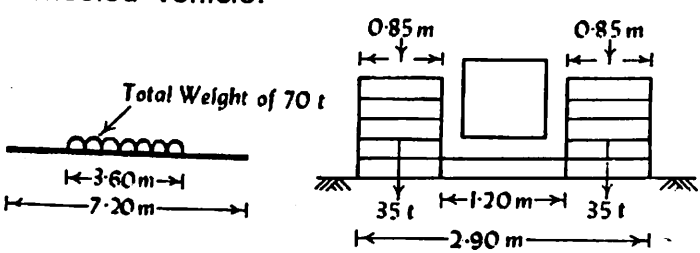
The I.R.C. has revised the old standard to meet with the requirements of the modern traffic. As per revised I.R.C. recommendations, the loadings are divided into the following *four* categories:

(i) Class *AA* loading
(ii) Class *A* loading
(iii) Class *B* loading
(iv) Class 70*R* loading.

(i) *Class AA loading:* The I.R.C. class *AA* loading is based on the heavy military vehicles likely to run on certain routes. It is to be adopted for bridges within municipal limits in certain existing industrial areas, certain specified highways, etc. It is the usual practice to design the structures on National and State Highways for Class *AA* loading. It is also desirable that the structures designed for Class *AA* loading should be checked for Class *A* loading because under certain conditions, it is likely to get heavier stresses under Class *A* loading.

In Class *AA* loading, the following *two* types of vehicles are specified:

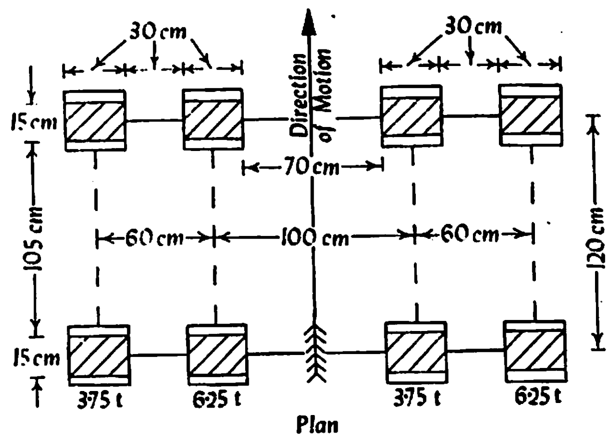
(a) Tracked vehicle
(b) Wheeled vehicle.



I.R.C. Class *AA* loading—tracked vehicle
FIG. 8–3

Fig. 8–3 shows the tracked vehicle. It consists of a packed load of 70 t which is equally distributed over two tracks of 0.85 m width. The length of vehicle is 7.20 m and out to out distance between the tracks is 2.90 m.

Fig. 8–4 shows the wheeled vehicle. The maximum load for single axle is 20 t and for double axles at 1200 mm centre, it is 40 t. The maximum wheel load is 6.25 t.



I.R.C. Class *AA* loading—wheeled vehicle
FIG. 8–4

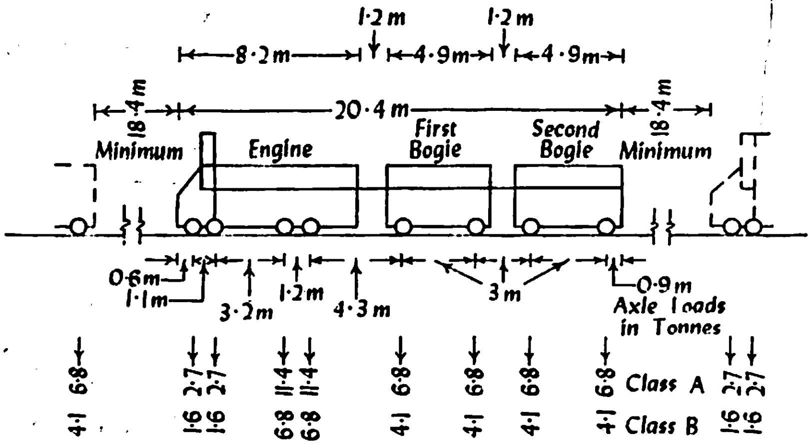
After considering the vehicles likely to cross the bridge, the choice is made either for tracked vehicle or wheeled vehicle. It is to be assumed for the design purpose that no other live load covers any part of the carriageway of bridge, when a train of tracked vehicle or wheeled vehicle is passing over it.

The nose to tail spacing between two successive vehicles should not be less than 90 m and the minimum clearance between the road surface of the kerb and the outer edge of the wheel or track should be as shown in table 8–3.

TABLE 8–3
CLEARANCE BETWEEN KERB AND OUTER EDGE OF WHEEL

Width of carriageway (cm)	Minimum clearance (cm)	Remarks
380 and above	30	Single lane bridges
Less than 550	60	Multi-lane bridges
550 and above	120	

(ii) *Class A loading:* The I.R.C. Class *A* loading is based on the heaviest types of commercial vehicle which is considered likely to run on the Indian roads. Hence, all important permanent road bridges and culverts, which are not covered by Class *AA* loading, are to be designed for Class *A* loading.



I.R.C. Class *A* and Class *B* loading
FIG. 8–5

Fig. 8–5 shows the train for Class *A* loading. It consists of an engine and two bogies. The specified axle loads with specified distances are also shown in fig. 8–5. The axle loads are assumed to act simultaneously so as to cause maximum stresses. The train is assumed to move parallel to the length of bridge. No other live load is to occupy any part of the carriageway of bridge when the standard train is crossing the bridge.

The ground contact area of the wheels for axle loads shown in fig. 8–5 for Class *A* and Class *B* loadings shall be as given in table 8–4.

TABLE 8–4
GROUND CONTACT AREA OF THE WHEELS

Axle loads (tonnes)	Ground contact area	
	B (mm)	*W* (mm)
11.4	250	500
6.8	200	380
2.7	150	200
4.1	150	300
1.6	125	175

The minimum clearance *f* between the outer edge of the wheel and the face of roadway kerb; and the minimum clearance *g* between the outer edges of passing or crossing vehicles on multi–line bridges shall be as given in table 8–5.

TABLE 8–5
MINIMUM CLEARANCES *f* and *g*

Clear width of carriageway (cm)	*f* (cm)	*g* (cm)
550 to 750	15 for all carriageway widths	Uniformly increasing from 40 to 120
Above 750	– do –	120

Following points should be noted:

(a) Footways: The footways and floors of bridge, which are accessible only to pedestrians and animals, are to be designed for a live load of 4 kN per m^2. The footways of bridges near crowded towns or at pilgrimage centres or at places where fairs are held seasonally, the design is based on a live load of 5 kN per m^2.

(b) Successive trains: The minimum distance between the successive trains shall be 18.4 m and no live load shall cover the space between the successive trains. The standard loads are to be arranged in such a manner that severest bending moment or shear is produced at the section under reference.

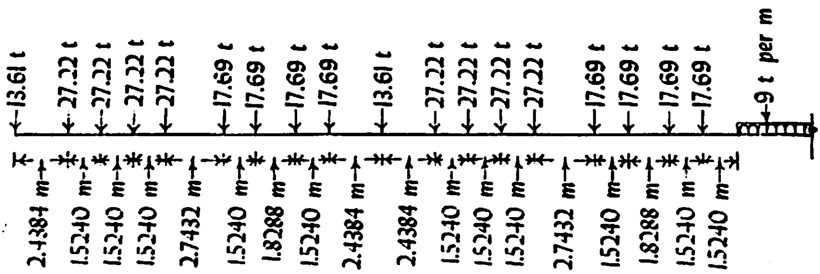
Traffic lanes: The specified wheel load train is for single lane of 3.048 m width. For design purposes, the traffic lanes upto 3.6576 m width will be considered as single lane of 3.048 m width and traffic lanes from 5.4864 m to 7.3152 m width shall be considered as double lanes of 6.096 m width. For other road widths i.e. from 3.6576 m to 5.4864 m and width exceeding 7.3152 m, the corresponding fraction shall be applied.

(iii) *Class B loading:* The method of application and other details of class *B* loading are same as class *A* loading. It is to be adopted for the design of temporary structures such as timber bridges, etc.

(iv) *Class 70R loading:* This is an additional loading which is sometimes specified for use in place of Class *AA* loading. The letter '*R*' indicates revised classification and it is based on one of the various other hypothetical vehicles as per revised classification. This loading consists of tracked vehicle and wheeled vehicle. The tracked vehicle is similar to I.R.C. Class *AA* loading except that ground contact length is 4.57 m, length of vehicle is 7.92 m and minimum spacing between successive vehicles is 30 m. The wheeled vehicle is 15.22 m long and it contains seven axles with the loads totalling to 100 tonnes. In addition, the effects on the components due to a bogie loading of 40 tonnes are also considered.

For railway bridges:

(1) *Cooper's class loading of America:* The Cooper's standard loadings are specified for the railway bridges by the American Engineers' Association and many existing bridges in India are designed with Cooper's standard loadings. Fig. 8–6 shows Cooper's E–60 loading. The uniformly distributed load of 9 t per m at the end is to be taken for the remaining length of span upto a maximum of 182.88 m. The other loadings such as E–40, E–50, etc. can be easily prepared. For instance, for E–50 loading, multiply axle loads of E–60 loading by the factor $\frac{50}{60} = 0.833$.



Cooper's E–60 loading

FIG. 8–6

(2) *Indian Railway Board:* The Indian Railway Board, Ministry of Railway, Govt. of India, has specified the standards of live loading to be adopted for three different gauges, namely, B.G., M.G. and N.G. The I.R.S. Bridge Rules contain various standards in detail and they also furnish tables giving the equivalent uniformly distributed loads (E.U.D.L.) in tonnes on each track and also the impact factors applicable for different spans. Hence, for ordinary bridges, the designer can safely adopt these E.U.D.L. because these loads are framed to give maximum moments and shears as would be obtained by the use of more complicated wheel loads. Thus, the design procedure is considerably simplified by E.U.D.L.

The standards of loading for the Railway Bridges are grouped as follows:

(1) B.G.	..	(a)	Main line
		(b)	Branch line
(2) M.G.	..	(a)	Main line
		(b)	Branch line
(3) N.G.	..	(a)	'H' class (Heavy)
		(b)	'A' class Main line
		(c)	'B' class Branch line.

For foot–bridges and foot–paths on the railway bridges, the live load due to pedestrian traffic including impact is taken as 4.80 kN/m^2 of the foot–path area. Following live loads are assumed for the design of main girders or trusses of the railway foot–bridges:

(1) For effective span of 7.50 m or less, the live load is taken as 4.10 kN/m^2.

(2) For effective span between 7.50 m and 30 m, the intensity of live load is estimated as gradually reducing from 4.10 kN/m^2 for 7.50 m to 2.90 kN/m^2 for 30 m.

(3) For effective span exceeding 30 m, the live load is worked out by the application of the following formula:

$$P = \left(13.3 + \frac{400}{L}\right)\left(\frac{17 - W}{1.4}\right)$$

where P = Pedestrian live load in kg/m^2

L = Effective span of the bridge in m

W = Width of the foot–way in m.

If the pedestrian live load is expressed in kN/m^2, the expression would be as follows:

$$P = \left(13.3 + \frac{400}{L}\right)\left(\frac{17 - W}{1.3}\right)$$

If the width of side kerbs is less than 600 mm, no other live load is to be considered. But for side kerbs having width of 600 mm or more, a lateral load acting horizontally at the top of the kerb and of value 7.50 kN per m run should be taken in addition to the pedestrian load of 4.80 kN/m^2.

IX. Longitudinal forces:

It is necessary to make suitable provision in the design of road bridge or railway bridge for the longitudinal forces which develop from any one or more of the following causes:

(1) the braking effect resulting from the application of brakes on the vehicles;

(2) the frictional resistance offered to the movement of free bearings due to variation in temperature or any other causes; and

(3) the tractive effort caused through the acceleration of the driving wheels of the vehicles or locomotives.

In India, the following rules are observed:

(1) *For road bridges:*

The braking effect is computed as follows for working out the longitudinal forces:

(i) *For single lane and two–lane bridge:* It is taken as equal to 20% of the first train load plus 10% of the loads in succeeding trains or parts thereof on any one lane only. For this purpose, the train loads in one lane only are considered. If the entire first train is not on the full span, it is taken as 20% of the loads actually on the span. The allowance for impact is not included in this computation.

(ii) *For multi–lane bridge:* In case of bridges with lanes more than two, it is taken as equivalent to the amount worked out as per provisions in (i) above for the first two lanes plus 5% of the loads on the lanes in excess of two.

The force due to braking effect is assumed to act along a line parallel to the roadways and 1200 mm above it and hence, it is transferred to the bearings accordingly.

The longitudinal force at free bearings due to the frictional resistance is worked out by multiplying the sum of the dead and live load reactions at the bearing with the appropriate coefficient of friction.

(2) *For railway bridges:*

The Indian Railway Board Bridge Rules contain tables giving values of longitudinal forces for different spans and for different standard loadings for different gauges of the Indian Railways. Suitable values for longitudinal forces are to be taken in the design by referring to these tables.

X. Secondary stresses:

In case of R.C.C. structures, the secondary stresses are developed due to the following causes:

(1) deformation of certain members,
(2) movement of the supports,
(3) shrinkage in concrete,
(4) time yield in concrete, etc.

In case of steel structures, the secondary stresses are developed due to the following causes:

(1) application of loads at intermediate points in a panel;
(2) cross–girders being connected away from the panel points;
(3) eccentricity of the connections of floor and beams;
(4) effect of wind load on end posts of through bridges;
(5) movement of the supports; etc.

The bridges should be designed and constructed in such a way that the secondary stresses are brought down to a minimum level. For other cases, necessary allowance should be made in the design for the secondary stresses.

XI. Seismic load:

When a bridge is situated in a locality which is likely to be affected by earthquakes, necessary allowance is to be made in the design of bridge for seismic load. The bridge is provided with structural features which are capable of resisting the effects of earthquakes.

The seismic load is taken as a horizontal force equal to a certain percentage of the weight of structure. The equation to find out the lateral force due to earthquake is as follows:

$$S = x\,W$$

where S = Lateral force due to earthquake

x = Seismic coefficient for the region

W = Weight of mass under consideration ignoring reduction due to buoyancy or uplift.

For the purpose of determining the seismic coefficient, the country is divided into *five* zones and table 8–6 shows the horizontal seismic coefficients to be adopted for different zones according to the type of soil. The zone I consists of areas which are not liable for earthquake damage. The zone V consists of areas subjected to severe earthquakes. The other zones comprise areas in the intermediate category between the above two extreme cases.

TABLE 8-6
HORIZONTAL SEISMIC COEFFICIENTS

No.	Zone no.	Horizontal seismic coefficient		
		Hard soil	Medium soil	Soft soil
1.	I	0.00	0.02	0.02
2.	II	0.02	0.02	0.04
3.	III	0.04	0.05	0.06
4.	IV	0.05	0.06	0.08
5.	V	0.08	0.10	0.12

The important facts to be remembered while considering the seismic load are as follows:

(1) The seismic load is considered to act in any horizontal direction through the centre of gravity of the structure as a whole and it is suitably and conveniently divided among members of substructures and superstructures for the purpose of design. The effect of the worst combination of seismic load with other loads is to be considered. The vertical seismic coefficient, if to be considered in the design of a bridge, may be taken as half of the horizontal seismic coefficient.

(2) For superstructure of bridge, the seismic force due to live load in the direction perpendicular to the traffic is only considered and the one in the direction of traffic is ignored.

(3) In case of piers of a bridge, the seismic force is assumed to act separately in direction parallel to the current of flow and in traffic directions.

(4) The superstructure of a bridge, especially in zones IV and V, should be suitably anchored to the piers so that dislodging of its bearings is prevented at the time of an earthquake.

(5) For piers of a bridge, the seismic load may be worked out on the basis of depth of scour caused by mean annual flood. For the purpose of design, it may be assumed that the mean annual flood and earthquake do not occur simultaneously.

(6) If masonry arch bridges are to be built in zones III, IV and V, they should not have spans greater than 10 m.

(7) The bridges such as bascule bridges and suspension bridges are to be carefully studied with respect to the effect of seismic load.

XII. Temperature variation forces:

Due to variation in temperature, the length of a structure is affected. If the change in length of a member due to variation in temperature is restrained, the temperature stresses are developed. But if allowance is kept to accommodate such change in length, the structure will not be subjected to temperature stresses.

The stress due to change in temperature is given by the following expression:

$$s = e \alpha t$$

where s = Stress due to change in temperature in kg per cm^2

e = Modulus of elasticity in kg per cm^2

α = Coefficient of expansion per degree centigrade and it should be taken as 11.7×10^{-6} for steel and R.C.C. structures; and 10.8×10^{-6} for plain concrete structures

t = Variation of temperature in °C.

Following points should be noted:

(1) *Concrete structures:* In case of concrete structures, it is necessary to consider the interval between the air temperature and the interior temperature of massive concrete. Unless otherwise specified, the range of temperature for concrete structures is taken as follows:

For moderate climate ± 1.1°C.

For cold climate ± 7.2°C.

(2) *Metal structures:* Unless otherwise specified the range of temperature for metal structures, is taken as follows:

For moderate climate – 1.1°C to + 48.9°C.

For cold climate – 17.8°C to + 48.9°C.

(3) *Temperature variation:* The temperature at the time of construction or erection of bridge should be considered as base for counting the temperature variation. It is necessary to see that the temperature variation is decided by studying the meteorological records of the locality in which the bridge is to be constructed.

XIII. Water pressure:

The portion of bridge which is submerged in running water is designed for horizontal forces of the water current. The water pressure is calculated by considering the hydraulic principles.

For piers parallel to the direction of the water current, the intensity of pressure is given by the following formula:

$$P = Kw \times \frac{V^2}{2g}$$

where P = Intensity of pressure due to water current in N per m^2

w = Unit weight of water in N per m^3

V = Velocity of the current in m per second

g = Acceleration due to gravity in m per sec^2

K = Constant.

With the usual values of $w = 9.81 \times 10^3$ N/m^3 and $g = 9.81$ m per sec^2, the above equation reduces to:

$$P = K \times 9.81 \times 10^3 \times \frac{V^2}{2 \times 9.81} = 500\ KV^2.$$

The value of V is assumed to vary linearly from zero at the point of maximum scour to the square of the maximum velocity at the free surface of water. For this purpose, the maximum velocity at surface is to be taken as equal to $\sqrt{2}$ times the maximum mean velocity of the current.

The value of constant K will depend on the shape of pier and its value is to be adopted as shown in table 8-7.

TABLE 8-7
VALUES OF CONSTANT *K*

No.	Shape of pier	Value of *K*
1.	Square ended piers	1.50
2.	Circular piers or piers with semi-circular ends	0.66
3.	Piers with triangular cut and ease waters with included angle between the faces as	
	30° or less	0.50
	more than 30° but less than 60°	0.50 to 0.70
	more than 60° and upto 90°	0.70 to 0.90
4.	Piers with cut and ease water of equilateral arches of circles	0.45
5.	Piers with arches of the cut and ease waters intersecting at 90°	0.50
6.	Trestle type piers	1.25

When the current of flow strikes the pier at an angle i.e. when the pier is not parallel to the direction of flow of water, the velocity of the current is resolved into *two* components—one parallel and the other normal to the pier. The pressure on face area of pier is worked out by considering the parallel component of velocity of the current and the pressure on side area of pier is worked out by considering the normal component of velocity of the current. The pressures are computed by adopting suitable value of K in the above formula.

In order to provide for the possible change in the direction of the current of flow, the bridge piers are designed for inclination of 20 degrees on either side to the existing direction of the current of water.

XIV. Wind load:

The wind load is directly proportional to the square of the velocity and it is expressed as follows:

$$P = KV^2$$

where P = Wind pressure in N per m^2

V = Velocity of wind in km p.h.

K = Constant which depends on meteorological conditions and nature of surface exposed to wind. Its value varies from 0.051 to 0.095.

For V = 112 km p.h. and K = 0.080

$P = 0.080 \times (112)^2$

= 1003.52, say 1000 N per m^2.

The provision for wind load is made in the design of bridge as follows:

For road bridges:

(1) The wind pressure is considered for the various components of bridge such as cross–girders, stringers, main girders, etc.

(2) The wind pressure is considered on the moving vehicles of live load. The wind load is assumed to act at a height of 1500 mm above the roadway on the moving vehicle and for highway bridges, its amount is taken as about 3 kN per m. It should be observed that for the purpose of their calculation, the clear distance between the trailers of a train of vehicles is not omitted.

(3) The effect of wind load is neglected for plate girders, R.C.C. slab and beam construction, slab of R.S.J. upto 18 m span, etc. But in all such cases, the lateral bracing is provided to resist a horizontal wind load of about 9 kN per m.

For railway bridges:

The basic wind pressure is determined either from the meteorological records or by referring to suitable table and no live load is to be considered when the basic wind pressure at deck level exceeds the following limits:

B.G. bridges	.. ..	1.5 kN/m^2
M.G. and N.G. bridges	.. ..	1.0 kN/m^2
Foot–bridges	.. ..	0.75 kN/m^2.

The effect of wind pressure is considered as a horizontal force acting in such a direction that the resultant stresses are the maximum for the member under consideration. The other design aspects of wind load are contained in the Indian Railway Board Bridge Rules and they should be followed in the design of all the railway bridges.

Design of bridge foundations:

The design of bridge foundations is made by keeping in mind the forces, loads and stresses enumerated above. For bridges with open foundations and well foundations, the permissible increase in the pressure on soil under the various combinations of the various forces, loads and stresses is adopted as follows:

(1) The maximum bearing pressure due to any combination of forces, loads and stresses under item nos. I, II, III, V, VII, VIII, IX, XII and XIII should be worked out and it should be seen that this maximum bearing pressure does not exceed the safe bearing capacity of the soil.

(2) When the effect of seismic load (item no. XI) or wind load (item no. XIV) is considered in addition to the forces, loads and stresses of item nos. I, II, III, V, VII, VIII, IX, XII and XIII, it should be seen that the maximum bearing pressure on soil does not exceed by 25 per cent of the safe bearing capacity of the soil.

(3) The seismic load and wind load are assumed not to act simultaneously.

(4) For the purpose of design of bridge foundations, the deformation stresses (item no. IV), erection stresses (item no. VI) and secondary stresses (item no, X) are ignored.

It may be mentioned that the world's longest road bridge exists in India. It was constructed with a total cost of about Rs. 46 crores and its length is 5.575 km. It is designated as Mahatma Gandhi Sethu on the Ganga and it connects north Bihar with the state capital Patna. It was completed in March, 1982. The bridge is spanning over 46 pillars. It consists of 45 spans of 121.06 m and two end spans of 62.53 m. It has a two–lane traffic system with a provision to expand it into four lanes. The superstructure consists of balanced cantilevers with an articulated bearing at mid–span. Each girder is made up of a single cellular box with depth varying from 7.9 m at piers to 2.16 m at the centre. The single circular wells have been used as foundation for carrying the cellular piers. The wells are of 12.5 m outside diameter with steining thickness of 1.85 m.

The Pamban road bridge, completed in 1988, connecting the island of Rameswaram with the main land in Ramanathpuram district of Tamil Nadu provides an excellent example of engineering achievement. This is India's only road bridge across the sea. It stands on 74 open foundations of which 64 are in the sea. It is about 2.4 km long and it is located at a distance of about 52 m south of an existing railway bridge. It also provides a navigation span of 115.21 m and to facilitate ship traffic, a vertical clearance of 17.68 m has been provided above the high tide level at the navigation span. There is a pedestrian platform also and from somewhere in the middle can be seen Gundukkal—the spot where Swami Vivekananda set foot on the country on his return from the U.S.A. after attending the Congress of World Religions.

QUESTIONS

1. Enumerate the various forces, loads and stresses which are to be considered in the design of a bridge.
2. What are the important facts to be remembered while considering the force of buoyancy?
3. Write short notes on:
   (1) Buoyancy pressure
   (2) Deformation stresses
   (3) Earth pressure
   (4) Erection stresses
   (5) B.S. unit loading
   (6) Cooper class loading of America
   (7) Coefficient of impact
   (8) Class 70*R* loading
   (9) E.U.D.L.

4. How is provision made for the centrifugal forces in the design of a bridge?
5. What is dead load? Mention some of the important empirical formulas which are used to find it.
6. What are stresses due to the impact?
7. Define the impact factor. Mention empirical formulas which are used to work out the impact factor for road bridges and railway bridges.
8. What are the points to be noted in connection with impact factors for the I.R.C. loadings?
9. What are I.R.C. specifications for the live load for road bridges?
10. How is provision made for the live load in railway bridges as per I.R.S. Bridge Rules?
11. What are the causes for the development of longitudinal forces? Explain the provision made for the longitudinal forces in the design of bridges in India.
12. How do the secondary stresses develop in concrete structures and steel structures?
13. What are the important facts to be remembered while considering the seismic load in the design of bridges?
14. Explain how temperature variation forces are considered in the design of a bridge.
15. How is provision made for wind load in the design of road bridges and railway bridges?
16. How are seismic load and water pressure considered in the design of a bridge?
17. Give sketches of the following:
    (1) Tracked vehicle of I.R.C. class *AA* loading
    (2) Wheeled vehicle of I.R.C. class *AA* loading
    (3) Train for I.R.C. class *A* loading.
18. Write a critical note on the design of bridge foundations.
19. Differentiate between the following:
    (1) I.R.C. Bridge Code and I.R.C. Bridge Rules
    (2) Dead load and live load
    (3) Deformation stresses and erection stresses
    (4) Impact load and impact factor
    (5) Tracked vehicle and wheeled vehicle
    (6) Zone I and zone V for seismic coefficients.

20. Give reasons for the following:

(1) the impact load is smaller on a large span than on a short span.

(2) It is desirable that the structures designed for Class *AA* loading should be checked for Class *A* loading also.

(3) For ordinary railway bridges, the designer can safely adopt E.U.D.L. as contained in the I.R.S. Bridge Rules.

(4) The bridge piers are designed for water pressure with an inclination of 20 degrees on either side to the existing direction of the current of water.

(5) The superstructure of a bridge, especially in zones IV and V, should be suitably anchored.

(6) The detailed design is carried out only in respect of the bridges with long spans and having very deep waterways.

Chapter 9

TEMPORARY BRIDGES

Definition:

The temporary bridges are defined as the structures which are constructed to cross a river or a stream in place of permanent works. Such bridges become useful when it is not possible to construct a permanent bridge due to shortage of money, time, good materials or skilled labour. The temporary bridges are often constructed on diversions during the reconstruction of an existing permanent bridge. The useful life of a temporary bridge is estimated as about 10 years.

In this chapter, the brief descriptions of the various types of the temporary bridges will be given.

Materials used:

The temporary bridges are generally constructed of timber. But it is possible to have temporary bridges made of hemp ropes, old rails, old telegraph posts, steel wires, etc. According to the Indian Roads Congress, all timber bridges are classified as temporary structures. The timber used in the construction of temporary bridges should be well–seasoned and free from any defects. It is also essential to have careful site inspection and control on the workmanship during their construction. The wooden bridges are likely to be easily damaged by fire or rot. The use of green timber should be avoided as it will shrink, lose weight, crack and warp. The available sizes and lengths of individual timber pieces should also be kept in mind as that would affect the spans for trestle bridges and panel lengths for trusses.

Fastenings used:

The fastenings which are used in the construction of temporary bridges are bolts and nuts with washers, drift bolts, hemp or wire ropes, iron spikes, nails, screws and patented connectors such as split rings, spike grids, etc. The bolts are to be provided with at least *two* steel washers having diameter equal to at least 2.5 times than that of bolt. The drift bolt is a round steel piece without head or point. The spikes should be driven in such away that they force their way into the connecting piece of timber. The patented connectors of different designs are being used increasingly in the important temporary bridges.

Types:

The temporary bridges can broadly be divided into the following *three* categories:

I. Bridges with intermediate supports
II. Bridges without intermediate supports
III. Floating bridges.

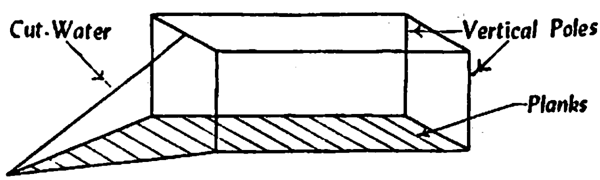
Each of the above category of bridges will now be briefly described.

I. Bridges with intermediate supports:

The intermediate supports for the temporary bridges are in the following forms:

(1) Crates
(2) Cribs
(3) Pile bents
(4) Trestles.

(1) ***Crates:*** A crate consists of *four* vertical poles which are connected at top and bottom by the horizontal members. The bottom is provided with planks and the sides are provided with wire netting so as to form a tray like structure for filling brushwood and stones to keep the crate in position. An inclined pole is sometimes provided on the upstream side to work as the cut–water. Fig. 9–1 shows the framework of a typical crate.

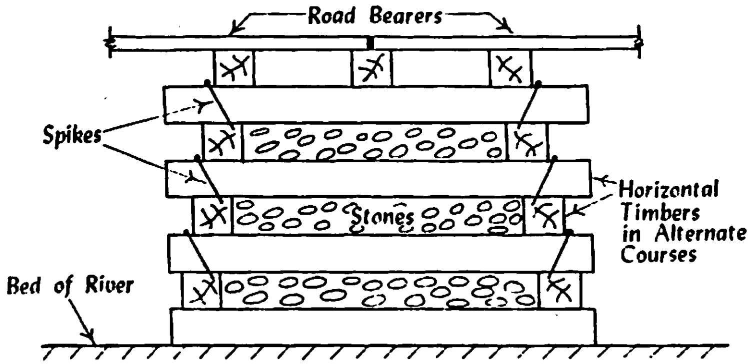


Crate
FIG. 9–1

The crate is constructed on the river bank. It is provided with wire netting on all sides. It is floated to the site and filled with brushwood or stones.

(2) ***Cribs:*** A crib is a box and it essentially consists of a framework of horizontal timbers laid in alternate courses. The bottom of crib is provided with planks. The pockets thus formed are then filled up with stones to give stability to the crib against overturning and sliding. The timber to be used in the construction of cribs may consist of rough logs or heavy lumber of the old sleepers from the railway. Fig. 9–2 shows a typical crib.

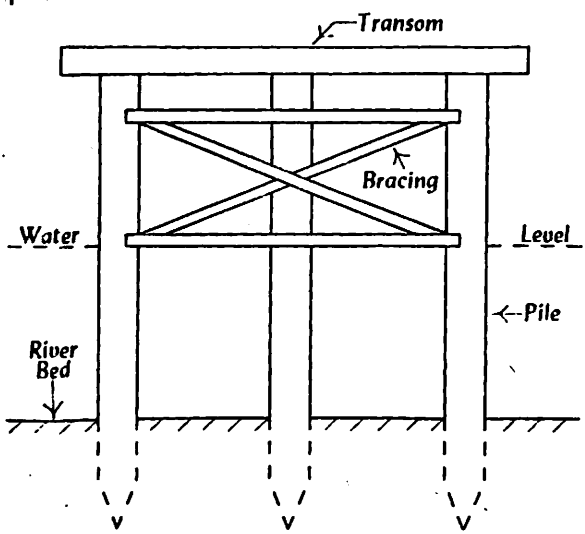
The cribs are useful as piers when the current of water is swift. They are constructed of cheap materials and they do not require skilled labour for their construction. Thus, they are found to be cheap and economical.



Crib

FIG. 9–2

The crib is constructed on the river bank. It is then floated on site and filled up with stones till it rests on the bed or river. The width of crib should be equal to the width of roadway plus 500 mm or so.



Pile bent

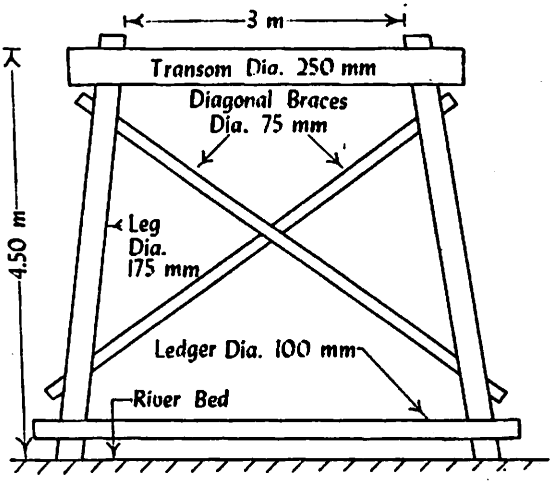
FIG. 9–3

(3) ***Pile bents:*** A pile bent is a group of piles and the number of piles in pile bent will depend on the load coming on the pier. The piles are of wood and they are

driven sufficiently deep so as to rest on firm ground. At suitable height, the piles are cut off and provided with pile cap or transom as shown in fig. 9–3. Suitable bracing may be provided as required. The pile bents are useful for deep streams with soft bed material. It is found that the pile bents form strong and stable piers.

(4) ***Trestles:*** The trestles may either be two–legged or three–legged or four–legged. A two–legged wooden trestle is in common use. Fig. 9–4 shows a typical two–legged wooden trestle to carry a live load of 8.40 kN per m, the centre to centre distance between the trestles being 4500 mm. A transom is fixed horizontally across the legs near their tops and a ledger is fixed across the feet of legs.

The diagonal braces are provided in between transom and ledger. Such a construction grants the stability to the trestle against spreading and sinking. The three–legged trestles are adopted when the river bed consists of mud. But they are not suitable for uneven bottom surfaces of river bed. It also proves difficult to place them in position. The four–legged trestles, when placed at intervals, grant longitudinal stability to a two–legged long bridge. But they are heavy structures and hence, they are difficult to place in position.



Two–legged wooden trestle
FIG. 9–4

The trestles are useful as piers when the height does not exceed 6 m or so and when the bed of river consists of fairly firm and level ground.

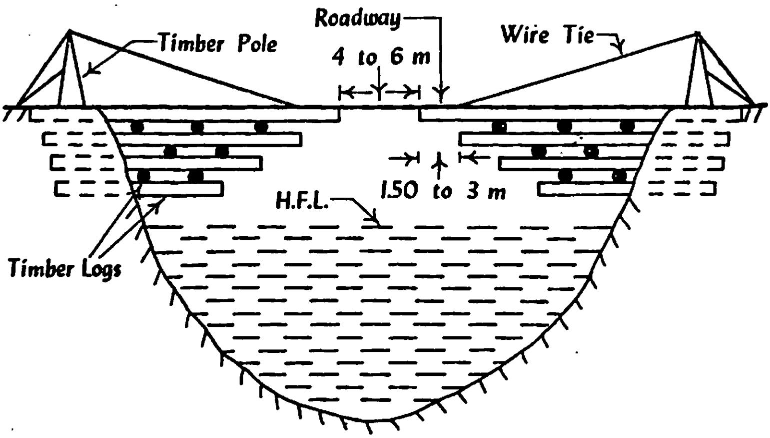
For dry beds or rivers with shallow depth of water, the trestles are constructed at site. Otherwise they are constructed on the river banks and carried on the boats to the site and lowered down in position.

II. Bridges without intermediate supports:

The temporary bridges may be designed to span the full width of river or stream with the help of the following:

(1) Cantilevers
(2) Suspension bridges
(3) Trusses.

(1) ***Cantilevers:*** In case of a timber cantilever bridge, the layers of timber logs are projected from each bank such that each layer projects about 1.50 m to 3 m from the layer just below it, as shown in fig. 9–5. The process of arranging the layers is continued till a gap of width about 4 m to 6 m remains. The gap is covered with the help of the road bearers to complete the bridge. The road surface is given suitable finish.



Timber cantilever bridge
FIG. 9–5

The timber cantilever bridges are very much useful and economical in the hilly areas where the timber is easily available and traffic is light. Following are the *advantages* of the timber cantilever bridges:

(i) It is possible to increase the load bearing capacity of the bridges by providing timber poles and wire ties as shown in fig. 9–5.

(ii) No costly constructional materials are required in the construction of the bridges.

(iii) No skilled labour or supervision is necessary during the construction of the bridges.

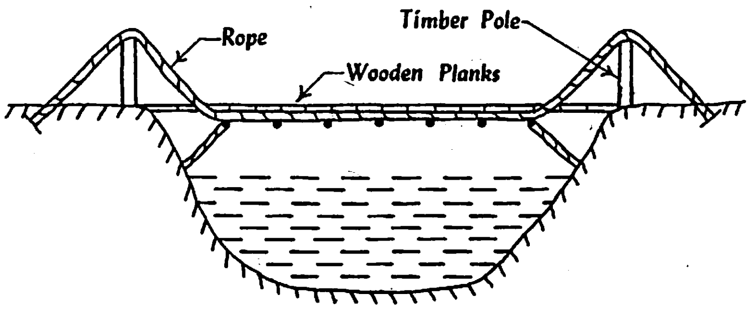
(2) *Suspension bridges:* For crossing small streams or valleys, the timber suspension bridges may be provided in the hilly area. The bridges can take up light traffic and they are usually not stiffened. Following are the *three* types of timber suspension bridges:

(i) Ramp bridge

(ii) Sling bridge

(iii) Trestle suspension bridge.

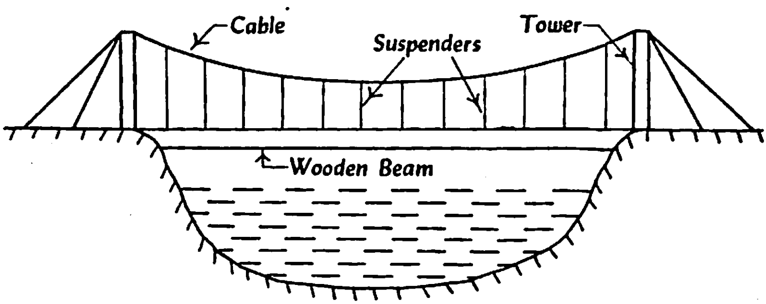
(i) *Ramp bridge:* In case of a ramp bridge, the roadway rests on cables as shown in fig. 9–6. As the bridge is connected with the banks by ramps or sloping lengths, it is known as *ramp bridge*. The bridge floor is provided with wooden planks. This type of bridge proves to be cheap in cost because it requires small quantities of materials and can be completed in short time with unskilled labour. The only disadvantage of this type of bridge is that it does not possess stiffness and hence, it is distorted when the traffic moves over it.



Ramp bridge
FIG. 9–6

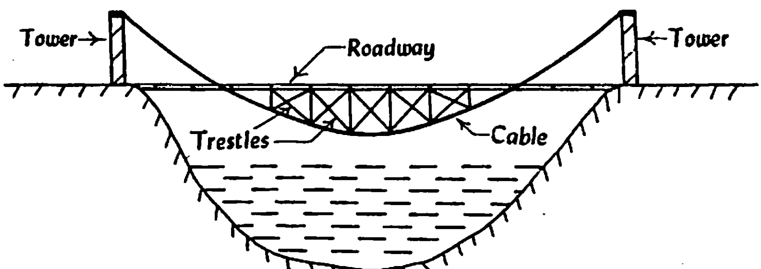
(ii) *Sling bridge:* In case of a sling bridge, the roadway is supported on rope slings or cables. The bridge floor consists of wooden planks which are supported at their ends on wooden beams. On either side of roadway, a wooden beam is provided. The wooden beam is connected to the cable through suspenders as shown in fig. 9–7. The cables are taken over the towers and they are then suitably anchored into the ground. The bridge railing is fixed to the suspenders.

The load from the bridge floor is transferred to the wooden beam and it is conveyed to the cables through the suspenders. This is the common type of temporary suspension bridge.



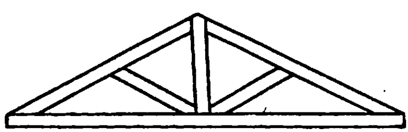
Sling bridge
FIG. 9–7

(iii) *Trestle suspension bridge:* In case of a trestle suspension bridge, the cable supports the trestles as shown in fig. 9–8. The trestle suspension bridge does not distort under traffic, but its weight is comparatively more.



Trestle suspension bridge
FIG. 9–8

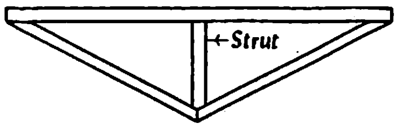
(3) *Trusses:* For long span timber bridges, the trusses are employed and with the help of timber trusses, it is possible to construct timber bridges for spans upto 14 m to 18 m. Fig. 9–9 to fig. 9–12 show some of the timber trusses.



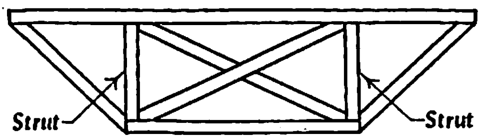
King–post truss
FIG. 9–9

Fig. 9–9 shows a king–post truss and it is useful for the through type bridges.

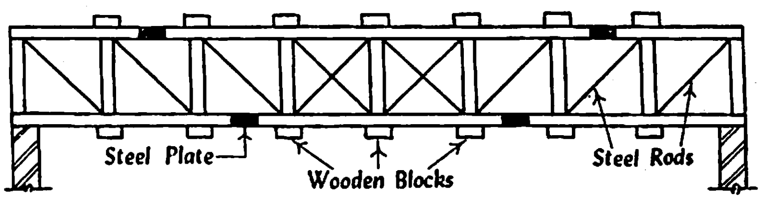
Fig. 9–10 shows a trussed beam with one strut and fig. 9–11 shows a trussed beam with two struts. Such trusses are useful for the deck type bridges.



Trussed beam with one strut
FIG. 9–10



Trussed beam with two struts
FIG. 9–11



Wooden girder
FIG. 9–12

Fig. 9–12 shows a wooden girder which can be used for spans upto 18 m. For connecting wooden members, the steel plates are employed and for taking tensile stresses, the steel rods are provided.

III. Floating bridges:

In case of floating bridges, the superstructure of bridge is supported on floating supports and hence, a modern floating bridge essentially consists of the following *two* parts:

(1) Floating supports or pontoons

(2) Superstructure.

The floating supports are placed at regular intervals along the bridge with their main axis parallel to the current of the river and they are designed in such a way that they possess enough buoyancy to take up the live load on the bridge. The spacing of pontoons should neither be too close nor too far. In the former case, there will be obstruction to the floating debris in the river and it may cause danger to the safety of bridge. In the later case, the sizes of members of the superstructure will become uneconomical. Hence, the design should aim at appropriate spacing of pontoons to achieve the maximum benefits with the minimum cost. Sufficient anchorage should be provided to the pontoons on upstream and downstream sides so as to maintain the alignment of bridge against the river currents.

The superstructure provides the roadway and when all parts are connected, it forms a continuous member. The load of vehicle moving on the bridge is conveyed to the pontoons on either side of the roadway.

The general requirements of a floating bridge can be enlisted as follows:

(1) It should be composed of strong, durable and non–corrosive material.
(2) It should be connected to the banks of river with properly designed adjustable ramps so that the rise or fall of water level in the river will not disturb the functioning of bridge.
(3) It should be possible to easily replace the damaged parts of the bridge.
(4) The bridge should be of such composition that it can be easily constructed and dismantled.
(5) The bridge should contain minimum number of different types of components.
(6) The components of the bridge should be inter–changeable.
(7) The level of completed bridge should be low, if it is desired to conceal it at short notice as in case of war.
(8) The size and weight of each component of bridge should be such that it can be easily handled and moved.

Following are the *advantages* of the floating bridges over the fixed bridges:

(1) It is possible to construct, use and dismantle a floating bridge between sunset and sunrise. Such facility proves to be extremely useful in war time to cross the streams or rivers without the knowledge of the enemy.

(2) They can be built at places where it is not possible to place crib or piers.

(3) They can be constructed speedily. As a matter of fact, these bridges can be assembled and used during hours of darkness and can be dismantled before sunrise. They are thus less vulnerable to enemy attack than the fixed bridges.

Following are the situations which are considered favourable for the construction of floating bridges:

(1) to accommodate the temporary traffic during festivals in the holy river bed;

(2) to facilitate the movement of army across stream, lake or river during war times;

(3) to serve the locality where the traffic is minor and seasonal and the river itself is subjected to floods during short periods only, not exceeding 3 months of the year, when the traffic on the road can safely be suspended.

(4) to serve the purpose of a permanent bridge, except during monsoon, at places where it is not possible to put up a permanent bridge for lack of funds or some .such reasons;

(5) to transport men and materials for the construction work of the permanent bridges; etc.

Depending on the type of floating support, the floating bridges are of the following *three* categories:

(1) Boat bridges

(2) Pontoon bridges

(3) Raft bridges.

(1) *Boat bridges:* In case of a boat bridge, the superstructure of bridges is supported on the boats. The boats are longitudinally connected by the trussed beams which are known as the *gunwales*. At the outer edges of boats, the gunwale pieces are provided to act as bearing plates for gunwales as shown in fig. 9–13. The transverse wooden planks are laid over the gunwales to form the roadway.

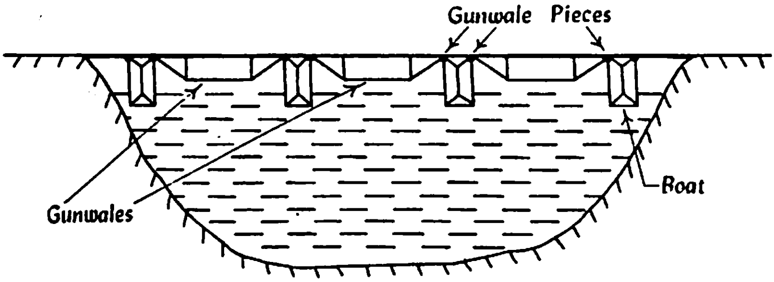
To impart rigidity and safety to the bridge, the following precautions are taken:

(i) The boats may be provided with anchors on upstream side and downstream side.

(ii) The complete bridge is stiffened by providing two longitudinal cables which run along the outer edges of boats.

(iii) The two gunwale pieces of the same boat are connected together with the help of crossed beams.

(iv) The two sides of the roadway are provided with parapet of steel or wooden poles with steel chain or rope passing through them.



Boat bridge
FIG. 9–13

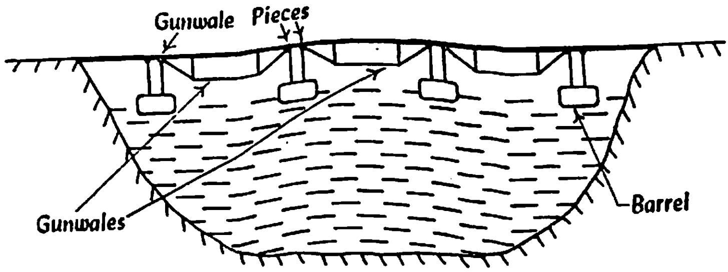
(2) *Pontoon bridges:* A pontoon bridge is similar to a boat bridge except that the pontoons are used in place of boats as supports of the bridge. A pontoon is a boat with flat bottom and in recent application, inflatable rubber pontoons have been used in place of the conventional wooden or metal barges. The pontoon bridges are used as the temporary bridges across wide rivers.

The pontoon bridges are superior to the boat bridges and they can carry more load as compared to the boat bridges. But the cost of pontoon bridges is comparatively more.

(3) *Raft bridges:* A raft bridge indicates a bridge made of rafts. A raft is a flat floating mass of wooden logs. Thus, the superstructure of a raft bridge is similar to a boat bridge. The substructure consists of barrels or casks which are connected to the gunwales at their tops. The raft bridge is, therefore, sometimes referred to as the barrel bridge. A barrel or cask is a hollow metal drum which is floating in the water. The long spars may be laid across the top of barrels or casks to maintain them in line. Fig. 9–14 shows a raft bridge.

In addition to the above usual types of the temporary bridges, sometimes the unit–type construction or Bailey bridges are also adopted. The superstructures of these bridges are normally made up of assemblable units which can be carried in units, assembled and launched in a short period over a gap. The unit–type construction bridges are useful under the following circumstances:

(1) The damage has occurred to a permanent bridge due to the approaches or even a part of the bridge is damaged leaving a wide gap.
(2) The traffic has been suspended and the permanent repairs to the bridge are likely to take a long time.
(3) The short–term movement of an army is required.



Raft bridge
FIG. 9–14

QUESTIONS

1. Define a temporary bridge and mention the materials and fastenings employed in its construction.
2. How can temporary bridges be constructed with intermediate supports?
3. Write short notes on:
   (1) Cribs
   (2) Trestles
   (3) Sling bridge
   (4) Ramp bridge
   (5) Pontoon bridges
   (6) Boat bridges
   (7) Unit–type bridges.
4. Describe the timber cantilever bridges.
5. Discuss the temporary suspension bridges.
6. How are trusses useful in the construction of temporary bridges?
7. Give sketches of the following:
   (1) Crate
   (2) Pile bent
   (3) Two–legged wooden trestle
   (4) Trestle suspension bridge
   (5) Boat bridge
   (6) Raft bridge.

8. What are the essential parts of a floating bridge?
9. Mention the general requirements of a floating bridge.
10. What are the advantages of floating bridges?
11. What are the favourable situation for the construction of a floating bridge?
12. Describe the various types of floating bridges.
13. What are the precautions to be taken to impart rigidity and safety to the boat bridges?
14. Differentiate between the following:
    (1) Crate and crib
    (2) Pile bent and trestle
    (3) Ramp bridge and sling bridge
    (4) Boat bridge and pontoon bridge
    (5) Raft bridge and barrel bridge.
15. Give reasons for the following:
    (1) An inclined pole is sometimes provided on the upstream side of the crate.
    (2) The timber cantilever bridges are very much useful and economical in the hilly area.
    (3) The spacing of pontoons in case of floating bridges should neither be too close nor too far.
    (4) The pontoon of floating bridge should be provided with sufficient anchorage on upstream and downstream sides.
    (5) The floating bridge should be connected to the bank of river with properly designed adjustable ramps.
    (6) The floating bridges prove extremely useful in war time.
    (7) The pockets formed in the cribs are filled up with stones.
    (8) The long spars may be laid across the top of barrels or casks of a raft bridge.
    (9) The use of green timber should be avoided in the construction of wooden bridges.
    (10) The floating bridges are less vulnerable to enemy attack than the fixed bridges.

Chapter 10

BEARINGS

Definition:

The devices which are provided over the supports of bridge to accommodate the changes in the main girders due to deflection, temperature, vertical movement due to sinking of the supports, shrinkage, prestressing creep, etc. and to transmit the load from the superstructure to the substructure in such a way that the bearing stresses induced in the substructure are within permissible limits are known as the *bearings*. Thus, the bearings are provided for the distribution of the load evenly over the substructure material which may not have sufficient bearing strength to bear or take up the load of superstructure directly.

In this chapter, some of the salient features of this important component of the bridge structure will be discussed.

Purposes:

Following are the purposes or objects of providing bearings in a bridge:

(1) to absorb movements of girder,

(2) to allow for angular movements of girder due to deflection under the load,

(3) to allow for longitudinal expansion or contraction due to changes in the temperature,

(4) to distribute the load on a large area,

(5) to keep the compressive stress within safe limits,

(6) to make movements of girder harmless,

(7) to rotate at supports to accommodate the deflection of a simply supported girder under load,

(8) to simplify the procedure in design.

(9) to take up the vertical movement due to sinking of the support,

(10) to transfer horizontal forces developed due to application of brakes to the vehicles, etc.

Importance of bearings:

It should be remembered that the successful functioning of a bridge primarily depends on the design of its bearings. It is observed that faulty design or improper working of the bearings is the main cause of failure of many bridges that have collapsed. The design of bearing to be adopted for a particular bridge will mainly depend on the type of supports, length of the span and the type of superstructure.

The bearings form an important component of a bridge and hence, extreme care and skill should be exercised in its design, execution and maintenance. For major bridges, the cost of bearings roughly works out to about 10 to 15 per cent of the total cost of the bridge. Hence, there is ample scope of achieving economy by designing the bearings properly and carefully.

Free and fixed bearings:

The terms free bearing and fixed bearing are used to indicate the function which is executed from a particular bearing.

A free bearing is free to slide or move or roll and it thus allows longitudinal movement of the girder.

A fixed bearing is fixed in position, But it rotates according to the deflection of the structure which is being supported by it. Thus a fixed bearing allows free angular movement and it does not permit any longitudinal movement of the girder. The design of fixed bearing depends on the length of span, type of supports and type of superstructure.

Types of bearings:

Following are the commonly adopted bearings for the bridges:

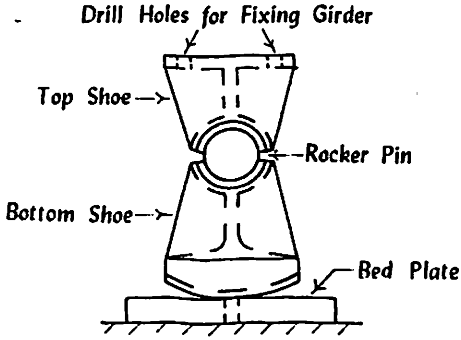
(1) Cement mortar pad
(2) Expansion bearing
(3) Knuckle bearing
(4) Rocker and roller bearing
(5) Rocker bearing
(6) Rubber bearing
(7) Sliding bearing
(8) Sole plate on curved bed plate bearing
(9) Tar paper bearing.

Each of the above type of bearing will now be briefly discussed.

(1) *Cement mortar pad:* This is the cheapest type of fixed bearing which is adopted for road girder bridges of small spans. It consists of a 30 mm thick cement grout pad of proportion 1:1. The dowel bars in sufficient number and of diameter about 25 mm are provided to connect the superstructure to the bed block. The length of the pad is made equal to the width of girder and its breadth along the span is kept in such a way that the pressure on the pad does not exceed 18 N/mm^2. The dowel bars are designed to take up the longitudinal forces in shear.

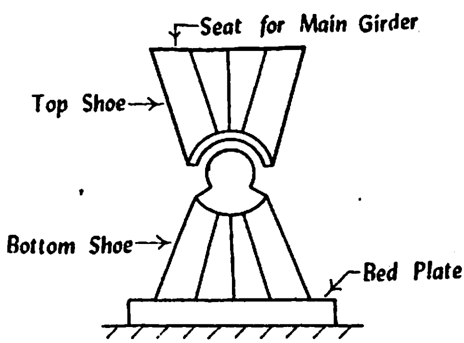
(2) ***Expansion bearing:*** In case of expansion bearing, the bottom shoe is given a circular shape. The centre of circular surface coincides with the centre of rocker pin. The bottom shoe rests on the bed plate. The top shoe is provided with drill holes for fixing of the girder.

Fig. 10–1 shows an expansion bearing. It allows free angular as well as longitudinal movement of the girder and it is useful for girders having small spans.



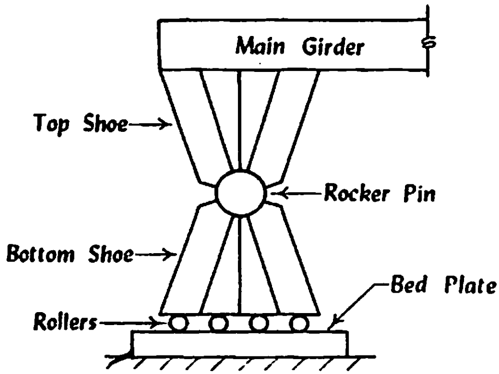
Expansion bearing
FIG. 10–1

(3) ***Knuckle bearing:*** In case of knuckle bearing, the top of bottom shoe and bottom of top shoe are given semi-circular shapes as shown in fig. 10–2. The knuckle bearing is adopted when it is desired to provide only for angular movement of the girder which is fixed to the top shoe.



Knuckle bearing
FIG. 10–2

(4) ***Rocker and roller bearing:*** In case of rocker and roller bearing, a rocker pin is provided between the top shoe and the bottom shoe and it is so arranged that the bottom shoe rests on rollers as shown in fig. 10–3. The rollers are cylindrical in shape and they are free to roll on steel bed plate. A rocker and roller bearing is therefore a free bearing which does not slide, but which rolls as well as rocks over a smooth bed plate.



Rocker and roller bearing
FIG. 10–3

The use of rocker and roller bearing is generally recommended when lengths of span exceed about 15 m or so. The important facts to be remembered in the design of a rocker and roller bearing are as follows:

(i) The initial setting of rollers in position should be carefully done. Otherwise they may not remain truly vertical.

(ii) The load from the bridge should evenly be distributed over one or several rollers in both directions, namely, longitudinal and lateral.

(iii) The number of rollers, their diameter and the choice of material should be made with respect to the load likely to come on the bearing.

(iv) The piers or abutments should be provided at their tops with a seat in the form of bed block or bed plate to receive the rollers.

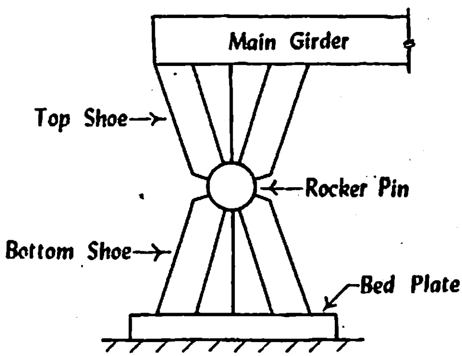
(v) The rollers, depending upon the design, may either be solid or ribbed. In case of a ribbed roller, the number of vertical ribs are held together by means of a horizontal pin to form one single roller.

(vi) The rollers should be placed in such a position that their constant movement will not cause the displacement of rollers.

(vii) The rollers should be readily accessible for lubrication and cleaning.

(5) *Rocker bearing:* A fixed bearing which rocks about a pin like a hinge is known as a rocker bearing. In case of a rocker bearing, a rocker pin is provided between the top shoe and the bottom shoe as shown in fig. 10–4. A rocker bearing allows only free angular movement of the main girder and at the same time, it transmits the pressure centrally to the bed plate.

For spans greater than 20 m or so, a rocker bearing is provided at one end and at the other end, a rocker and roller bearing is provided.



Rocker bearing
FIG. 10–4

(6) *Rubber bearing:* A rubber bearing consists of layers of rubber plates. The steel plates or wire–meshes are introduced between the successive layers and a minimum cover of about 5 mm of rubber is maintained along the edges. The steel plates or wire–meshes perform *two* functions:

(i) the chance of relative sliding between the rubber plates is avoided; and

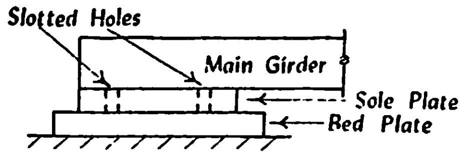
(ii) the crushing of rubber under the load is prevented.

The desired thickness of rubber bearing can be obtained by selecting a proper number of rubber plates. The synthetic rubber like Neoprene can be successfully used for preparing rubber bearings.

If a thick rubber bearing is provided at one end and a thin rubber bearing is provided at the other end, the former acts as a free bearing and the latter acts as a fixed bearing.

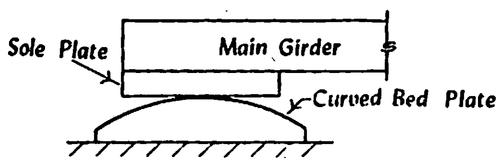
(7) ***Sliding bearing:*** In case of a sliding bearing, a sole plate is provided between main girder and bed plate as shown in fig. 10–5 and the girder is rigidly connected to sole plate.

The bed plate is fixed rigidly with the bridge supports by anchor bolts. The sole plate is attached to the bed plate by bolts through the slotted holes of the sole plate. The sliding bearing allows only longitudinal movement of the main girder.



Sliding bearing
FIG. 10–5

(8) ***Sole plate on curved bed plate bearing:*** In case of a sole plate on curved bed plate bearing, the main girder is fixed to the sole plate which rests on a curved bed plate as shown in fig. 10–6. Such a bearing is useful when it is desired to allow only free angular movement of the main girder.



Sole plate on curved bed plate bearing
FIG. 10–6

(9) ***Tar paper bearing:*** In a strict sense, the tar paper cannot be termed as a bridge bearing. But for very small length of span upto about 7 m or so, the tar paper can be used to perform the functions of a bearing. The paper offers considerable frictional resistance to displacement to the extent of about 50 per cent to 70 per cent.

Materials for bearings:

The bearings of the bridge are made of various materials. But following are the common materials which are generally used to manufacture the bridge bearings:

(1) Cast steel
(2) Lead
(3) Mild steel
(4) Reinforced cement concrete
(5) Rubber
(6) Tar paper.

The bearings of cast steel, mild steel and tar paper are very common in India. The design of an R.C.C. bearing is rather complicated. But its construction is cheaper and speedy. It can be cast as soon as it is ready. The reinforcement in case of R.C.C. bearings is usually of spiral type so that bursting tension can be effectively resisted.

As the metallic bearings are expensive in first cost and difficult to maintain, the recent trend is to adopt elastometric bearings. An elastomer is either natural rubber or a synthetic material possessing characteristics similar to the rubber. The synthetic rubber in common use is the chloroprene rubber known as 'Neoprene'. The natural rubber has the following drawbacks:

(1) It has only moderate weathering resistance.
(2) It is inflammable.
(3) It is likely to be attacked by oxygen, ozone, oils and fuels.

Following are the *advantages* of elastometric bearings:

(1) It is possible to increase their resistance against oxygen and ozone by adding antioxidants and antioxonants.

(2) The height of this type of bearing is minimum and far less than that of roller or rocker bearing. It thus leads to the reduction in the cost of the approaches.

(3) The removal and replacement, if required, can be carried out easily.

(4) They are easy to install, and low in first cost.

(5) They do not require positive fixing like metallic bearings.

(6) They have better weathering resistance and are flame resistant.

(7) They require practically no maintenance.

Bed blocks:

The bearings rest on pier cap and hence, there is concentration of stresses at surfaces where the bearings are placed. In order to distribute effectively the stresses, the bed blocks of cement concrete are prepared to function as seats for the bearings. A bed block is a distributing block of rich concrete placed at the top of pier. It is usually made about 80 mm large in all directions of the contact area. The term bed plate is used to indicate a bed block of steel.

Maintenance of bearings:

The bearings should be properly maintained so as to keep them effective during their useful life.

In case of steel bearings, it should be examined that the bearings have sufficient lubrication and there is residual wet grease between moving parts or contact surfaces. Where the oil baths are used for the bearings, it should be checked to see whether the level of oil is correct and the covers are properly in position so as to prevent the entry of external material to contaminate the oil. If the grease or oil is badly contaminated with dust, it should be cleaned and fresh grease or oil should be added.

The metallic bearings, in addition, should be examined to ascertain whether:

(1) the anchor bolts are in position and not loose or bent;

(2) the movement is as anticipated or excessive;

(3) there is any rusting and seizing of the plates;

(4) there is any structural crack either in the constituents of the rollers themselves or in the supporting members like the bed block, pier cap, etc.

The bearings should normally be greased once in *three* years and the last date of greasing should be prominently marked on the face of the girders close to the abutments.

The use of elastometric bearings has become popular and they are being most extensively used on the road bridges and are being introduced on large scale on small span railway bridges also. They should be inspected to ascertain the following:

(1) general cleanliness of the bearings and their surroundings with special reference to keep them away from grease, oil, petrol, etc.; and

(2) physical condition of the pads like flattening, bulging. splitting, creep and evidence of oxidation.

QUESTIONS

1. Define a bearing and mention the purposes of providing bearings in a bridge.
2. What is the importance of bearings?
3. What are the free and fixed bearings?
4. Explain the expansion bearing and the knuckle bearing.
5. Give sketches of the following:
   (1) Expansion bearing
   (2) Knuckle bearing
   (3) Rocker and roller bearing
   (4) Sliding bearing.
6. What are the important facts to be remembered in the design of a rocker and roller bearing?
7. Write short notes on:
   (1) Rubber bearing
   (2) Sliding bearing
   (3) Sole plate on curved bed plate bearing
   (4) Tar paper bearing
   (5) Bed blocks
   (6) Elastometric bearings
   (7) Cement mortar pad bearing.
8. What are the materials used for bearings?
9. How are the different types of bearings maintained?
10. Differentiate between the following:
    (1) Free bearing and fixed bearing
    (2) Knuckle bearing and rocker bearing
    (3) Expansion bearing and rocker bearing
    (4) Rubber bearing and tar paper bearing.
11. Give reasons for the following:
    (1) The successful functioning of a bridge primarily depends on the design of its bearings.
    (2) There is ample scope of achieving economy by designing the bearings of a bridge properly and carefully.
    (3) A fixed bearing allows free angular movement.
    (4) The steel plates or wire-meshes are introduced between the successive layers of a rubber bearing.

(5) The reinforcement in case of R.C.C. bearings is usually of the spiral type.

(6) The bed blocks are provided as seats for the bearings.

(7) The dowel bars in sufficient number are provided in the cement mortar pad bearing.

(8) The top shoe of expansion bearing is provided with the drill holes.

(9) A rocker and roller bearing is a free bearing.

(10) The initial setting of rollers in position in case of rocker and roller bearing should be carefully done.

(11) The recent trend is to adopt the elastometric bearings.

(12) The adoption of elastometric bearings leads to the reduction in cost of the approaches.

(13) The bearings should be properly maintained.

Chapter 11

MISCELLANEOUS TOPICS

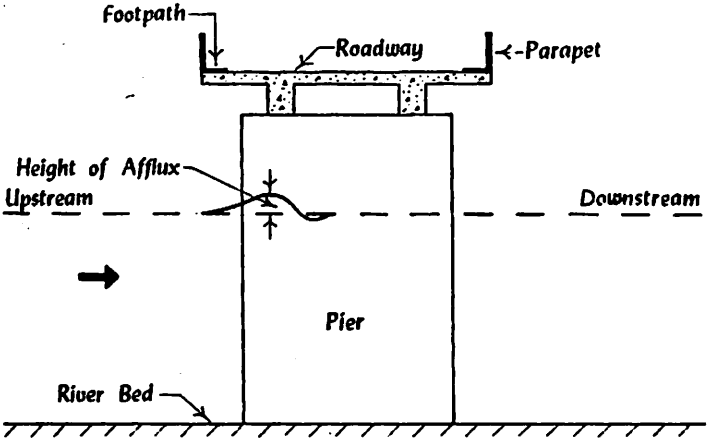
General:

In this chapter, the following miscellaneous topics of bridge engineering will be discussed:

I. Afflux
II. Approaches
III. Bridge architecture
IV. Clearance and freeboard
V. Combined road and railway bridges
VI. Economic span
VII. Erection of steel girders
VIII. Formwork for arch bridges
IX. Handrails
X. Joints
XI. Maintenance of bridges
XII. Posting of bridges
XIII. Rating of existing bridges
XIV. Rebuilding of bridges
XV. Testing and strengthening of bridges
XVI. Training works for bridges.

I. Afflux:

Definition: The abutments and piers of a bridge cause obstruction to the natural flow of river or stream. It results in the reduction of the natural waterway of river or stream. Hence, the velocity of flow under the bridge increases during maximum flood discharge. It is due to the fact that, as per law of continuity of flow in hydraulics, the multiplication of area and velocity remains the same at all sections in the flow of water. Now, the velocity is developed due to head of water and hence, to increase the velocity, there is sudden rise or heading up of water level on the upstream side of the bridge, as shown in fig. 11–1. Such rise of water level on the upstream side is known as the *afflux* and it is desirable to keep its value as far as possible to 150 mm. The afflux will also be caused when the effective lineal waterway of a bridge is less than the natural width of the stream immediately on the upstream side of the bridge.



Afflux
FIG. 11–1

Importance: It is necessary to calculate the afflux while designing a bridge for the following reasons:

(1) *Increased velocity:* Due to afflux, there is an increase in the velocity of flow under the bridge. It should be checked that such an increased velocity is within the permissible limit for the bridge. The greater the afflux, the greater will be the depth of scour and consequently, the depth of foundations will also be more. Similarly, the greater the afflux, the more will be the velocity produced through the obstruction.

(2) *Protective works:* If afflux is more, the protective works in the form of guide banks or training works, will be required for preserving the river embankments.

(3) *Submersion of bridge:* If due allowance is not made for afflux, it is likely that the bridge floor will be submerged during the period of maximum flood discharge.

Height of afflux: The increase in velocity due to afflux is governed by the following relation:

$$v_a = \sqrt{2g\ h_a}$$

where v_a = Velocity due to afflux in m per sec

g = Acceleration due to gravity in m per sec^2

h_a = Height of afflux in m.

To find out the value of h_a, the following *two* empirical formulas are generally used:

(1) *Merriman's formula:*

$$h_a = \frac{v^2}{2g}\left\{\left(\frac{A}{Ca}\right)^2 - \left(\frac{A}{A_1}\right)\right\}$$

where v = Natural or normal velocity of flow in the river in m per sec

A = Natural or normal waterway under the bridge in m^2

a = Actual or artificial waterway under the bridge in m^2

A_1 = Enlarged area upstream of the bridge in m^2

C = Coefficient of discharge which accommodates contraction and frictional losses occurring as water passes by the piers

$$= 0.75 + 0.35\left(\frac{a}{A}\right) - 0.10\left(\frac{a}{A}\right)^2 \text{ approximately.}$$

(2) *Molesworth's formula:*

$$h_a = \left(\frac{v^2}{17.87} + \frac{1}{65.60}\right)\left[\left(\frac{a}{A}\right)^2 - 1\right]$$

where v, A and a are same as above.

It may be mentioned that these *two* empirical formulas for finding height of afflux give satisfactory result only when the area of obstruction is not more as compared with the natural or normal uncontracted area.

For calculating the height of afflux, it becomes necessary to find out the natural or normal velocity of flow in the river and the natural or normal waterway of bridge site. For arriving at mean values of normal velocity and normal waterway, the measurements should be taken at sufficient distances on the upstream side of the bridge.

Problem 11-1.

The normal velocity of flow in a river is 1.50 m per sec. The normal waterway under the bridge, the artificial waterway under the bridge and enlarged area upstream of the bridge are respectively 8000 m^2, 7000 m^2 and 10000 m^2. Assume g = 9.81 m per sec^2. Calculate the height of afflux and increase in velocity due to afflux by applying (i) Merriman's formula and (ii) Molesworth's formula.

Solution:

(i) *Merriman's formula*

$$h_a = \frac{v^2}{2g}\left\{\left(\frac{A}{Ca}\right)^2 - \left(\frac{A}{A_1}\right)\right\}$$

where h_a = Height of afflux in m

v = Normal velocity of flow in m per sec

= 1.50 m per sec

g = Acceleration due to gravity in m per sec^2

= 9.81 m per sec^2

A = Normal waterway under the bridge in m^2

= 8000 m^2

a = Artificial waterway under the bridge in m^2

= 7000 m^2

A_1 = Enlarged area upstream of the bridge in m^2

= 10000 m^2

C = Coefficient of discharge

$= 0.75 + 0.35\left(\frac{a}{A}\right) - 0.10\left(\frac{a}{A}\right)^2$ approximately

$= 0.75 + 0.35\left(\frac{7000}{8000}\right) - 0.10\left(\frac{7000}{8000}\right)^2$

$= 0.75 + 0.31 - 0.08$

$= 0.98.$

Substituting,

$$h_a = \frac{(1.50)^2}{2 \times 9.81}\left\{\left(\frac{8000}{0.98 \times 7000}\right)^2 - \left(\frac{8000}{10000}\right)\right\}$$

$$= \frac{2.25\ (1.36 - 0.80)}{2 \times 9.81}$$

$= 0.0642$ m. . . . . *Ans.*

Now, $v_a = \sqrt{2g\,h_a}$

where v_a = Velocity due to afflux in m per sec

g = 9.81 m per sec^2

h_a = 0.0642 m.

Substituting,

$v_a = \sqrt{2 \times 9.81 \times 0.0642}$

h = 1.122 m per sec. . . . . *Ans.*

(ii) *Molesworth's formula:*

$$h_a = \left(\frac{v^2}{17.87} + \frac{1}{65.60}\right)\left[\left(\frac{A}{a}\right)^2 - 1\right]$$

where h_a = Height of afflux in m

v = Normal velocity of flow in m per sec

= 1.50 m per sec

A = Normal waterway under the bridge in m^2

= 8000 m^2

a = Artificial waterway under the bridge in m^2

= 7000 m^2.

Substituting,

$$h_a = \left(\frac{1.50^2}{17.87} + \frac{1}{65.60}\right)\left[\left(\frac{8000}{7000}\right)^2 - 1\right]$$

$$= (0.1259 + 0.0152)\ (1.306 - 1)$$

$$= 0.0432 \text{ m}$$ .... *Ans.*

Now, $v_a = \sqrt{2g\ h_a}$

where v_a = Velocity due to afflux in m per sec

g = 9.81 m per sec^2

h_a = 0.0432 m.

Substituting,

$$v_a = \sqrt{2 \times 9.81 \times 0.0432}$$

$$= 0.92 \text{ m per sec.}$$ .... *Ans.*

II. Approaches:

Any bridge carries either a roadway or a railway line. The alignment and level of some portion of the roadway or railway line on either side of the bridge will be required to be suitably altered to make a connection of roadways or railway lines on either side of the bridge. The approach road is defined as that part of the roadway or railway line whose alignment will be altered as a result of the new bridge to be constructed.

Following important points should be remembered in connection with the approaches of bridge:

(1) *Borrow pits:* If the approach is in filling, it is to be seen that the borrow pits are not very near to the embankment. If this precaution is not taken, there are chances of parallel flow being developed which may even endanger the safety

of the embankment proper. Depending upon the topographical features and size of the channel, the minimum distance from the toe of embankment and depth of borrow pits should be suitably specified.

(2) *Construction:* The approaches may either be in embankments or in cutting. It is always preferable to have approaches in embankment rather than in cutting. However, when approaches are in cutting, the single span bridge or suspension bridge is adopted. The soil to be used for filling in the embankment should be carefully selected and it should be seen that it does not contain excessive clay.

(3) *Cost:* The cost of construction of approach road is considered as the part of the bridge project itself.

(4) *Curvature:* If the approaches are situated on curvature, it should be seen that the curve is smooth and easy. In any case, the approaches with dangerous curves should be avoided. The curves are to be provided beyond the minimum straight length of the approaches. The introduction of horizontal or vertical curves should be made in accordance with the relevant I.R.C. Road Standards.

(5) *Extension of bridge:* To provide better substructure to the approaches, the bridge as such is extended into the banks for some distance. The extended portion however may not have the same type of superstructure as the bridge proper.

(6) *Gradient:* The approaches should not have gradient more than the ruling gradient. Generally, 1 in 30 to 1 in 20 gradient is specified for the approaches. It is desirable for the approaches to be level for some distance beyond the end of bridge proper. In any case, the provision of steep gradients on the approaches should be avoided.

(7) *Joint walls:* The embankments of approaches should be carefully joined with the bridge and it is desirable to construct the joint walls between the approaches and the bridge.

(8) *Maintenance:* The approaches are to be maintained with special care especially when they are newly constructed. The approach banks and protection works should be such as to involve minimum recurring maintenance expenditure. They should also be reasonably free from flood damages because in such cases, the approach will be put out of use for long periods and will involve high cost in restoration.

✓(9) *Width and length:* The approaches should normally be made wider than the bridge. As per I.R.C. recommendations, the approaches should have at least a minimum straight length of 15 m on either side of a bridge. This minimum length may be increased in cases where it is required to provide minimum sight distance for the design speed. Also, the minimum straight length of the approaches should be surfaced for a width at least equal to the width of roadway on the bridge itself.

III. Bridge architecture:

The essential consideration of a bridge is its functional utility. But at the same time, it is desirable to make the bridge design aesthetically pleasing by observing some of the principles of architectural planning. The engineer and architect should work together to develop good aesthetics of bridge design.

The foundation portion is buried and not exposed to view always or most of the time. The piers and abutments are exposed to view and in combination with the superstructure, the entire bridge should provide a pleasing view.

The bridges are permanent structures which will stand for decades and some have even been existing over a few centuries. The bridge aesthetics is a matter of taste and it is difficult to codify the rules to be adopted in this respect. As in other art forms, this expression is also personal. A poem does not come from a committee nor a painting from collaboration even though there are editors and assistants who may influence the final work. There are enough individuals practising bridge design as artists to justify a belief that personal expression can lead to better designs.

Following are some of the aspects of bridge architecture:

(1) *Construction:* The bridge should be constructed with such materials and finishing items that is functionally adequate, economic in cost and pleasing in appearance. The rendering of exposed external surfaces should be done with taste. In the early stages, the bridges were constructed of stone rubble masonry with components well proportioned and left always exposed to give a good appearance. With the advent of bricks, the bridges were made of brick masonry to a large extent to achieve a good aesthetic appearance. Later on, the cast–iron which could span longer lengths was tried by the engineers to have a pleasing appearance in combination with the substructure. With the advent of R.C.C. and prestressed concrete, a new vista has been opened for the engineers to develop a bridge structure with strong architectural appeal.

(2) *General design:* The various components of bridge such as road approaches, carriageways, footpaths, etc. should be suitably proportioned with each other to develop a sense of beauty. The arrangement of these components should form a harmonious mass of beauty.

(3) *Landscaping:* The surrounding landscape features such as trees, lawns, etc. should be properly exposed to secure a pleasant landscaping. In fact, the bridge should be tastefully designed and thoughtfully located in harmony with the existing landscaping of the locality.

(4) *Light and shade:* The role of light and shade on bridge at night is certainly a matter of expression. The highways and bridges within city limits should be provided with diffused lights so that a vehicle driver can put off his vehicle light well ahead before reaching the bridge and can enjoy the ride over the bridge.

(5) *Lines and edges:* The eye of an observer appreciates the lines and edges employed in the bridge structure. It is therefore essential that all lines and edges are in good order to contribute to the pleasure imparted by a bridge view.

(6) *Proportioning:* The span and depth of the bridge should be suitably proportioned. The main dimensions and choice of spans are however largely determined by the functional and economic considerations. But a variation within reasonable limits is permissible to achieve an attractive design. In all cases, a bridge should look as effortless as possible and not too heavy. A well proportioned bridge not only looks attractive but also expresses a sense of achievement.

(7) *Railings:* The railings on bridge should be provided with such design that an open view is seen while crossing or driving over the bridge. The solid parapets may be used only for the single span minor bridges and culverts.

(8) *Simplicity:* The best bridge design should always exhibit a certain simplicity. The unnecessary ornamentation is meaningless in modern times because those who pass over or under the bridge usually travel at a speed and take pleasure in the general effect of the design.

IV. Clearance and freeboard:

Definition: The term vertical *clearance* is used to indicate the vertical distance between the springing level of arch or bottom of girder and the highest flood level. The term freeboard at any point is used to indicate the difference between the highest flood level after allowing for afflux, if any and the formation level of road embankment on the approaches or top level of guide bunds at that point. Thus, the vertical clearance is associated with the lowest point of the superstructure while the freeboard is connected with the approaches and bunds.

Necessity: Following are the *reasons* for providing the vertical clearance in all the categories of bridges:

(1) *Afflux:* The height of afflux is to be accommodated between the bottom of bridge and H.F.L. during the period of the maximum flood discharge. If clearance is not provided, there are chances for the bridge floor to be submerged at the time of maximum flood discharge.

(2) *Floating debris:* During the period of the highest floods, there will be floating debris in river water and the surface of water will be in the form of waves. The clearance is provided to allow the floating debris to pass safely under the bridge and to accommodate the height of waves between the bottom of bridge and H.F.L.

(3) *Navigation:* For rivers, streams or canals which are to be used for the purpose of navigation, the clearance should be provided so as to allow the vessels even during the period of maximum flood discharge and it has to be determined in consultation with the Inland Navigation Department of the State or Union Government, as the case may be.

Provisions: For clearance, the provisions which are usually made are as follows:

Arch bridges .... 300 mm
Girder bridges .... 600 mm to 900 mm
High level bridges .... 600 mm
Navigable rivers .... 2400 mm to 3000 mm.

With respect to the quantity or discharge of flow, the provision for the clearance is usually made as shown in table 11–1.

TABLE 11-1
MINIMUM VERTICAL CLEARANCE

No.	Discharge in m³ per second	Minimum vertical clearance (mm)	
		Road bridge	Railway bridge
1.	Below 0.30	150	600
2.	From 0.30 to 3	450	600
3.	From 3 to 30	600	600
4.	From 30 to 300	900	660
5.	From 300 to 3000	1200	1200
6.	Above 3000	1500	1800

Following points should be noted:

(1) For high level bridges, the freeboard should not be less than 600 mm.

(2) The provision of clearance may be relaxed in case of the irrigation channels at the discretion of the engineer in charge of the project.

(3) For structures provided with the metallic bearings, the clearance between the highest flood level including afflux and the base of bearings should not be less than 500 mm.

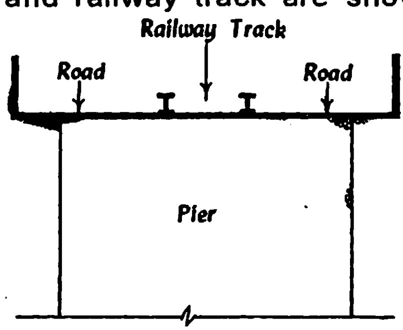
(4) For arch bridges, the clearance below the crown of the intrados of the arch should not be less than the result obtained by the following equation:

$$\text{Clearance} = \frac{1}{10} \times \text{maximum depth of the water} + \frac{1}{3} \times \text{rise of the arch.}$$

V. Combined road and railway bridges:

Sometimes, the same bridge is used to carry road as well as railway. Such a construction proves to be economical in the sense that instead of incurring foundation costs for *two* bridges, the foundation cost of only one bridge has to be incurred. It is quite, therefore, evident that the proposition of a combined road and railway bridge has to be entertained where foundation cost of a bridge forms a substantial portion of the bridge project.

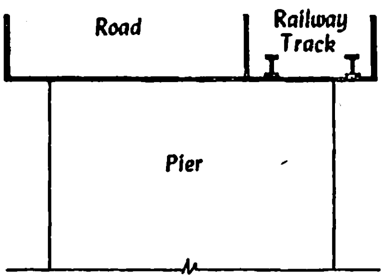
The various possible combinations with respect to the levels of roadway and railway track are shown in fig. 11–2 to fig. 11–9.



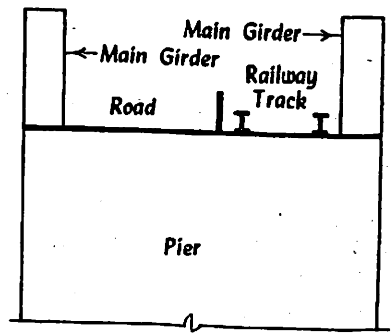
Road and railway—same level
FIG. 11–2

Fig. 11–2 shows the road and railway on the same deck. This type of combination is undesirable from the considerations of track maintenance, railway operation and road traffic. It can be adopted for bridges carrying light road traffic and unimportant railway tracks.

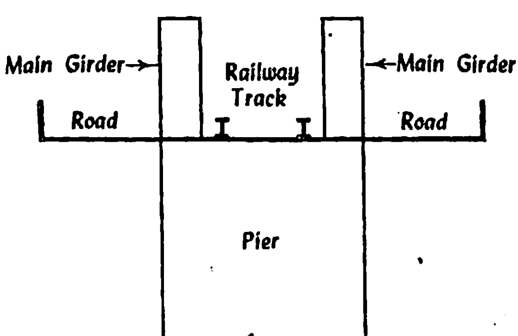
Fig. 11–3 shows road and railway side by side above main girders. Fig. 11–4 shows the road and railway side by side between main girders. As loading is eccentric, these combinations are usually not recommended. But they are to be considered for short bridges carrying a single lane of road traffic and having formation levels of the road and railway practically the same.



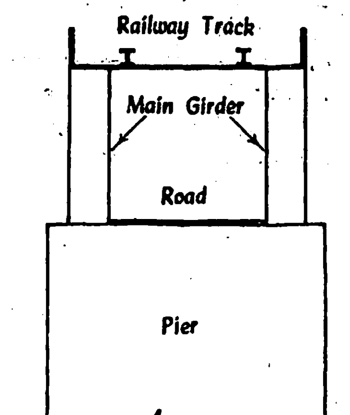
Road and railway side by side above main girders
FIG. 11–3



Road and railway side by side between main girders
FIG. 11–4



Cantilevered roads
FIG. 11–5



Railway above road and over top chords
FIG. 11–6

Fig. 11–5 shows *two* traffic lanes of road — one on either side — cantilevered from the main girders. The railway track is carried between the main girders. This type of combination is to be adopted for short bridges in flat country and it possesses the following *two* disadvantages:

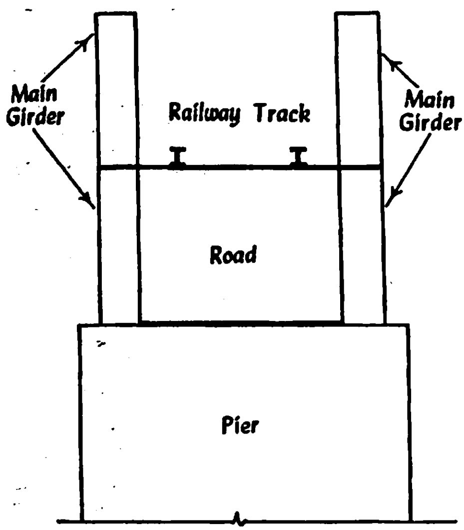
(1) The fast road traffic cannot overtake the slow road traffic on the bridge.

(2) The main girders are to be designed also for the eccentric loading, when only one road lane is occupied, resulting in uneconomical sections of the main girders.

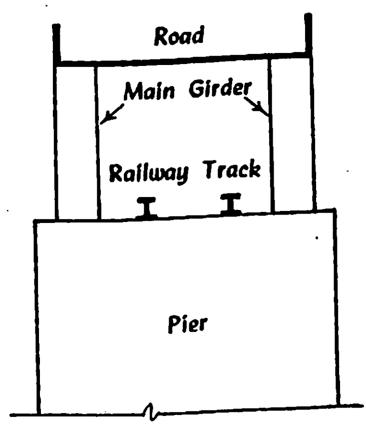
Fig. 11–6 shows the railway above road and over top chords. Such a combination is adopted in the hilly areas for spans upto about 75 m.

Fig. 11–7 shows the railway above road and between main girders. Such a combination is adopted in the hilly areas for spans greater than 75 m.

Fig. 11–8 shows the road above railway and over top chords. Such a combination is adopted for long bridges in flat country for spans upto about 60 m to 90 m.

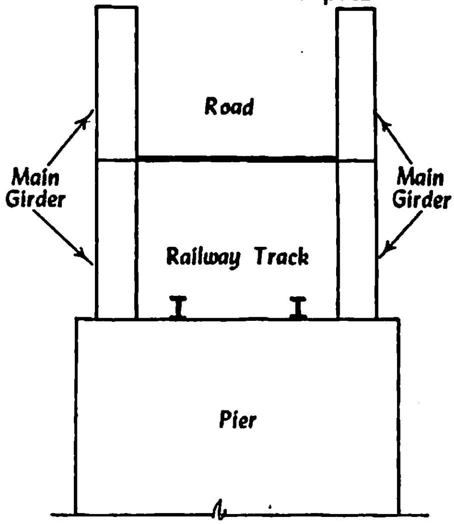


Railway above road and between main girders
FIG. 11–7



Road above railway and over top chords
FIG. 11–8

Fig. 11–9 shows the road above railway and between main girders. Such a combination is adopted for long bridges in flat country and for situations where it will be more convenient and economical to accommodate the road between the girders.



Road above railway and between main girders
FIG. 11–9

The longest rail–cum–road bridge of Asia exists on river Godavari in the State of Andhra Pradesh forming a link between *two* important towns — Rajahmundry and Kovvur. The project was a joint venture between the Indian Railways and the State Govt. It was put into commission on November 20, 1975 and it was constructed with a total cost of Rs. 12.22 crores. Some of the salient aspects of this bridge are as follows:

(1) *Airlock equipment:* For carrying out the work of pneumatic caissons, the *two* sets of highly sophisticated airlocks were imported from M/s Fries Sohn, Frankfurt, West Germany, at a cost of Rs. 10.63 lakhs.

(2) *Alignment:* To avoid the disturbance to the thickly populated and built–up area on Rajahmundry side, the last six spans are laid on sharp 6° curve. For accurate work, the sophisticated equipments such as tellurometer were employed by staff of Survey of India Department. The tellurometer is a compact transistorised instrument and works on the principle of reflection of the radio waves. It can measure straight distance upto 30 km with a maximum error of 10 mm or 3 parts per million of the length.

(3) *Foundations:* The twin piers of massive concrete on top of pneumatic caissons are of circular section of 4.27 m diameter. The depth of foundation is about 31 m below the low water level so as to ensure sufficient grip in the bed even under the conditions of maximum erosion during the high floods.

(4) *High tensile steel:* The huge quantity of high tensile steel, about 173 × 10^3 kN, was produced in India only and hence, this bridge became the first bridge to be constructed with indigenous high tensile steel.

(5) *Lighting on road:* For the safety of the vehicular traffic during nights, the road bridge is provided with adequate and well–designed illumination arrangement.

(6) *Section:* The bridge carries a single broad gauge track on the bottom deck and a double lane roadway of National Highway Standards on the top deck. The roadway also contains footpaths of 1.50 m width on either side. The total width of roadway is 7.50 m.

(7) *Superstructure:* The steel trusses of K–type with 12 m height are used in the superstructure. The girders were erected by the cantilever method which allowed the work to go on round the year without any interruption.

(8) *Total length:* The bridge is divided into 27 spans of 91.4 m and 7 spans of 45.7 m and the total length of the bridge is 2.90 km. Suitable approaches are provided on both sides.

The rail–cum–road bridge on river Godavari thus really stands as a speaking monument of the technical know–how and ingenuity of the Indian engineers.

VI. Economic span:

Definition: The centre to centre distance between successive bridge supports is known as the *span*. The term *economic span* is used to indicate the span which, if adopted, brings down the total cost of bridge to minimum with respect to the various factors affecting the cost of a bridge such as availability of materials of construction, labour charges, nature of waterway, availability of skilled labour, climatic conditions, etc.

Theory: It is possible to find out a mathematical expression for the economic span of a bridge with the help of the following assumptions:

(1) The bridge consists of equal spans.

(2) The bridge is an arch bridge or a girder bridge.

(3) The cost of abutments with their foundations is nearly constant.

(4) The cost of one pier with its foundation is nearly constant.

(5) The cost of superstructure per span varies directly as the square of span. This assumption is based on the fact that the design of superstructure mainly depends on the bending moment and the bending moment is directly proportional to the square of span.

Let L = Total length of bridge

l = Length of one span

n = Number of span = $\frac{L}{l}$

P = Cost of one pier with its foundation

C = Cost of bridge excluding cost of abutments.

Now,

Cost of bridge = Cost of superstructure + Cost of piers + Cost of abutments

∴ C = Cost of superstructure + Cost of piers .. (i)

According to the assumption no. (5),

cost of superstructure per span $\alpha\, l^2 = a\, l^2$

where a is the constant of variation.

∴ Cost of superstructure for n spans = $n\, a\, l^2$ ...... (ii)

As n indicates number of spans, the number of piers would be $(n - 1)$ and hence,

cost of piers = $(n - 1)\, P$ .... (iii)

Substituting (ii) and (iii) in equation (i),

$$C = n.a\, l^2 + (n - 1)\, P$$

$$= n.a \left(\frac{L}{n}\right)^2 + (n - 1)\, P$$

$$= \frac{a\, L^2}{n} + (n - 1)\, P.$$

For C to be minimum,

$$\frac{dC}{dn} = 0$$

∴ $$- \frac{aL^2}{n^2} + P = 0$$

∴ $$- a\, l^2 + P = 0$$

∴ $$P = a\, l^2 \quad \text{...................... (iv)}$$

From equation no. (iv), it is seen that the economic span for a bridge is one which is so selected as to make the cost of one pier with its foundation to the cost of superstructure per span or in other words, it means that an economic span is one in which the cost of one pier is equal to one–half of the cost of two spans which it supports.

For rivers subjected to heavy floods and at places where the foundations are to be expensive, the large spans are adopted. For gentle rivers and at places where good foundations are available at shallow depths, the small spans are adopted.

Exceptions: Following are the cases in which it is not possible to adopt the economic span as worked out from the above considerations:

(1) *Dead load of superstructure:* It is found that there is considerable increase in the dead load of superstructure beyond a certain value of span. Such an increase in dead load of the superstructure results in the increase in cost of bridge and it also causes difficulty in the erection of superstructure.

(2) *Foundations of piers:* It is likely that suitable foundations of piers are not available at the points where the piers are to be placed as per consideration of the economic span. As a matter of fact, the piers should be so located as to make the best use of the foundation conditions available at the bridge site.

TABLE 11-2
ECONOMIC SPAN AND HEIGHT OF PIERS

No.	Type of bridge	Relation between l and h
1.	R.C.C. slab on masonry piers	$l = 1.50\ h$
2.	R.C.C. slab and beam on masonry piers	$l = 1.75\ h$
3.	R.C.C. slab on pile bents	$l = h$
4.	Steel troughs on R.S. joists	$l = 1.50\ h$
5.	Steel trusses on masonry piers	$l = 3\ h$
6.	Masonry arch	$l = 2\ h$ or more

(3) *Height of piers:* There is some relation between economic span and total height of the pier. Table 11–2 shows the approximate values of the economic spans with respect to the lengths of piers for different types of bridges. The term l indicates economic span and the term h indicates total height of one pier from the underside of the foundation to the top of pier. For an arch bridge, the height is to be measured upto the intrados of the keystone.

(4) *Increase in span:* The relation for economic span holds good upto a certain value of span only. The cost of pier with its foundation per metre run is directly proportional to the mass of pier and it is found that there is considerable increase in the mass of pier beyond a certain value of span. It is therefore necessary to examine carefully the economic span before it is being adopted.

(5) *Miscellaneous reasons:* The economic span has to be suitably modified for various other reasons such as navigational requirements, aesthetic considerations, etc.

Problem 11-2.

The approximate costs of one pier and one superstructure span for a multiple span bridge for various lengths of span are tabulated as follows:

Span in m	Cost of one pier Rs.	Cost of one superstructure Rs.
10	25000	7000
15	28000	13815
20	32500	31000
25	33700	36000
30	34800	41400

Determine the economic span.

Solution:

Now, cost of superstructure $\alpha\ l^2 = a\ l^2$

where a = constant of variation

l = span.

The values of a for different costs will be as follows:

For 10 m span, $a = \frac{7000}{100} = 70.00$

For 15 m span, $a = \frac{13815}{225} = 61.40$

For 20 m span, $a = \frac{31000}{400} = 77.50$

For 25 m span, $a = \frac{36000}{625} = 57.60$

For 30 m span, $a = \frac{41400}{900} = 46.00$

∴ Average value of

$$a = \frac{70.00 + 61.40 + 77.50 + 57.60 + 46.00}{5}$$

$$= \frac{312.50}{5} = 62.50$$

Average cost of pier

$$= \frac{25000 + 28000 + 32500 + 33700 + 34800}{5}$$

$$= \frac{154000}{5} = \text{Rs. } 30800.$$

For span to be economic,

Cost of one pier = Constant × (Economic span)^2

∴ Economic span $= \sqrt{\frac{30800}{62.5}} = 22.20$ m. .... *Ans.*

VII. Erection of steel girders:

Preliminary: Before the erection of steel girders is started, the following important points should be carefully observed:

(1) *Centering:* In some cases, the centering or temporary supports will be required for erection of steel girders so as to take care of erection stresses, where necessary. The centering should be safe and it should be capable of being easily dismantled. Wherever possible, an attempt should be made to use portion of the permanent structures as centering.

(2) *Field forces:* It is absolutely necessary to organize properly the field forces which consist of machinery, materials and men. It should be so planned that there is no unnecessary delay of the work. In some cases, the members of a structure may be subjected to reversal of stresses during erection as compared to the final service load stresses. The designer should specify the precautions to be taken in the field under such circumstances.

(3) *Machinery:* The details of machinery required for erection of steel girders should be properly worked out and such machinery should be made available before the starting of work.

(4) *Measurement of span:* The exact span of steel girder should be measured at site and such measured span should be adopted for fabricating steel girder, marking positions of anchor bolts, bearings, etc.

(5) *Selection of method:* The various methods which can be adopted for erection of a particular steel girder should be studied and out of many alternatives, the most suitable method should be adopted.

Methods: Following are the methods of erection of steel girders:

(1) Building out from supports
(2) Floating
(3) Lifting
(4) Rolling
(5) Staging.

(1) *Building out from supports:* For erecting steel superstructures of cantilever type, it is possible to start the work from both the supports. The *two* portions are suitably connected by a hinge at the centre. The method of building out from supports can also be adopted for long span simply supported steel girders, if extra additional members are provided to take up the erection stresses.

The method is also known as the cantilevering method and it is used for very large spans. The erection starts from the abutment end and the erection of the members ahead is done:

(i) in case of prestressed concrete construction , by using the support on the previously erected part of structure; and

(ii) in case of steel construction, by using a crane which travels on the top boom of the previously erected part of the structure.

(2) *Floating:* When depth of water in river is more, the method of floating is generally adopted. In the method of floating, the pontoons are used to carry the steel girders. The pontoons carry bodily the fabricated steel girders from the shore and deposit them at site. Alternatively, the pontoons may be used to act as the temporary supports for girders while they are being pushed from the shore or support.

(3) *Lifting:* Following are the conditions favourable for the method of lifting:

(i) The height of superstructure above river bed should be moderate, say 4 m to 6 m.

(ii) The river bed is available in dry condition for major period of the year.

(iii) The span is within 30 m.

In the method of lifting, the fabricated steel girders are brought on the river bed and are assembled on a levelled platform which is formed by filling earth to sufficient height. They are then lifted up and placed in position with the help of cranes or shear legs or winches or some such arrangements. After placing the girders in position, the flooring and the bracings are than field connected to the girders.

(4) *Rolling:* For continuous bridges and for crossing a viaduct, the method of rolling out girders from the supports may be adopted. In the method of rolling, the girders are suitably rolled in position by providing necessary bearings on the supports. During the process of rolling, the erection stresses are set up and it is, therefore, necessary to provide adequate additional members to take up the erection stresses.

The method is also referred to as the incremental launching method and it has become very popular for the concrete girders. It can be used for both cast–in–situ construction and for precasting. It basically consists of the following procedure:

(i) The concrete bridge deck segment is manufactured in a pre–fabrication area behind one of the abutments.

(ii) Each new segment is concreted directly against the preceding one.

(iii) After the segment has hardened and stressed, the structure is jacked forward by the length of one segment.

(iv) The bridge unit is gradually pushed over the intermediate piers.

This is a highly mechanised bridge deck erection method. It permits considerable reduction in the investment cost of formwork and erection plant. However, the use of this method is very much dependent upon the labour and material costs prevalent in the area and the availability of necessary equipment. It also depends upon the access to site, span length, environmental factors, construction depth, etc.

The incremental launching method has been used quite extensively in our country for long spans of 90 m to 120 m over major rivers.

(5) *Staging:* Following are the conditions favourable for the method of staging:

(i) The depth of water in the river is shallow during the period of construction.

(ii) The height of superstructure above the river bed should not be excessive.

(iii) The span should be simply supported.

The staging consists of trestle frames which may be of wood or steel. The staging is suitably designed and after it is constructed, the erection of steel girders is commenced on the staging.

VIII. Formwork for arch bridges:

To construct arches, the centering will invariably be required. The type and design of centering will mainly depend on the following factors:

(1) availability of labour for constructing and erecting the centering,

(2) depth of water, liability to floods, etc.,

(3) distance required between supports of centering for the passage of traffic,

(4) foundation conditions,

(5) nature and type of arch i.e. span, rise, etc.,

(6) sizes and lengths of timber available, etc.

Good features: Following are the good features of a typical design for the centering of arch bridges:

(1) The centering should be of sufficient strength and rigidity. It will then be possible to keep such centering in line, level and shape during construction.

(2) The centering should be so arranged that it can be easily removed after the work is completed without causing any damage to the arch.

(3) The centering should be so prepared that the maximum quantity of material of centering may be recovered. It means that the centering should have a greater salvage value.

(4) The design of centering should be such that the combined cost of labour and material works out to be the minimum.

Types: The centering for the arch bridges can be classified into the following *three* categories:

(1) Steel truss centering

(2) Timber truss centering

(3) Trestle centering.

(1) *Steel truss centering:* In steel truss centering, the steel trusses of suitable shape and design are used. The design of steel trusses mainly depends on the nature of arch, method of construction, prevailing local conditions, etc. The handling of steel trusses may sometimes create problem. But it can be solved by using suitable modern machinery for the same. Following are the circumstances favourable for the steel truss centering:

(i) When arches are to be constructed in the rivers subjected to frequent heavy floods, it is found that the steel trusses will be less damaged due to the action of floods than the other types of centering.

(ii) When it is impossible or uneconomical to use trestle type of centering, the steel trusses are used.

(iii) When the depth of water is more, the steel truss centering is preferred to other types.

(2) *Timber truss centering:* In timber truss centering, the timber trusses of suitable shape and design are used. Following are the circumstances favourable for the timber truss centering:

(i) an arch is to be provided in gorge or deep valley,

(ii) the passage for traffic is required during the construction of arch, and

(iii) the supports for centering are to rest in deep water.

The trusses are however expensive to frame and there is little salvage value of the material. The timber trusses are also likely to deform under the load. In order to employ the timber trusses successfully, the following precautions are to be taken:

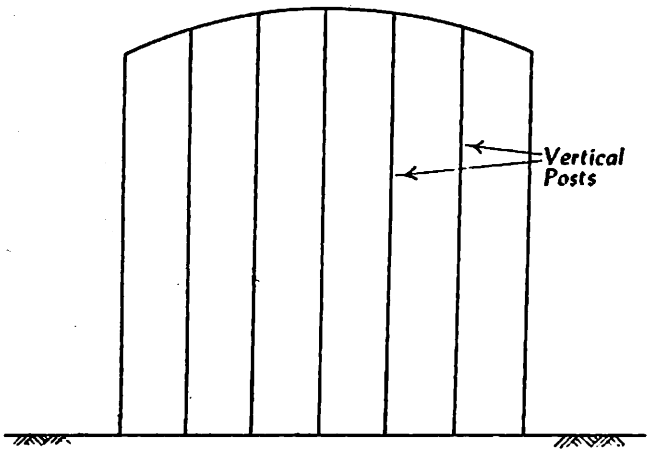
(i) It is necessary to find out the stresses developed in various members of the timber truss for different loadings which may occur during the construction of arch. One important fact to be noted is that some members of the truss may be subjected to reversal of stresses and such members should be adequately protected for the same.

(ii) One more intermediate supports may be given to the centering to reduce the amount of deflection.

(iii) The stiffness of timber truss is very important and it should be seen that the deflection does not exceed the maximum permissible value.

(iv) The timber truss should be accurately designed and carefully constructed.

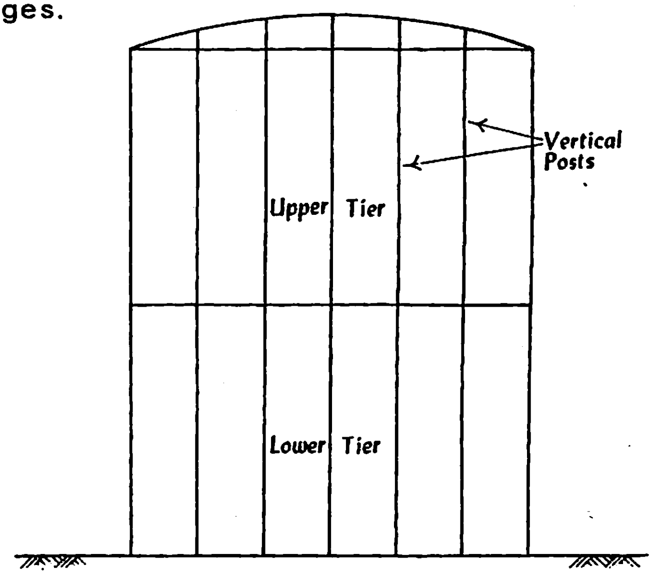
(3) *Trestle centering:* The term *trestle centering* is used to mean that the arch is supported by posts resting on the ground. The best arrangement would be of the vertical posts. But it is possible to arrange the trestle centering in a variety of forms as shown in fig. 11–10 to fig. 11–13.



Trestle centering
FIG. 11–10

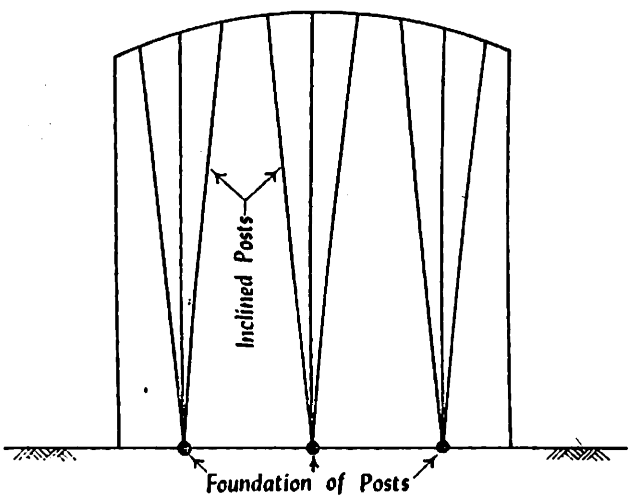
Fig. 11–10 shows the trestle centering in which the posts are vertical and they reach from ground to the arch in a single stage. Such an arrangement is useful for the arches of low bridges.

Fig. 11–11 shows the trestle centering which is built up in tiers. Such an arrangement is useful for the arches of high bridges.



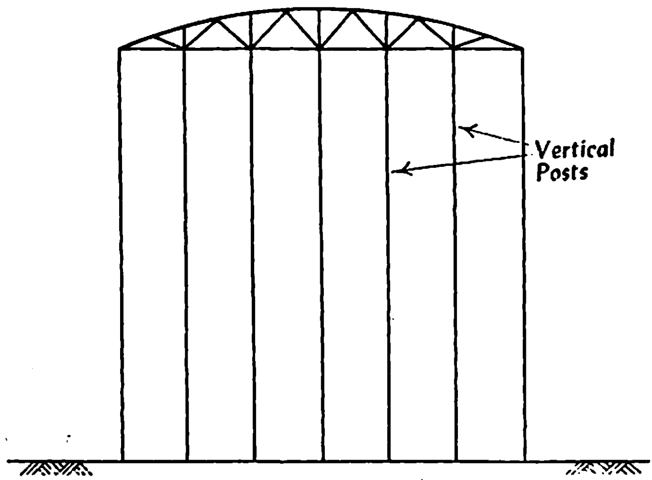
Trestle centering
FIG. 11–11

Fig. 11–12 shows the trestle centering with inclined posts. It is adopted when it is desired to cut down the number of foundation posts.



Trestle centering
FIG. 11–12

Fig. 11–13 shows the trestle centering which is a combination of fig. 11–11 and fig. 11–12. It is used when it is desirable to reduce the span of stringers without increasing the number of vertical posts.



Trestle centering
FIG. 11–13

Following are the *advantages* of the trestle centering:

(i) As compared to other types of centering, the cost of trestle centering is not more.

(ii) It deforms the least and hence, there are less chances of its failure.

(iii) It is simple in construction and can therefore be easily built.

(iv) It possesses the greatest salvage value of the materials used in its construction.

IX. Handrails:

The handrails or railings are necessary on the sides of a bridge to serve the following *two* purposes:

(1) The chances of bridge users and vehicles for falling into the stream or river will be considerably reduced by the presence of handrails at the sides of a bridge.

(2) They will define the width of bridge and if properly constructed, will impart an architectural character to the appearance of the bridge.

The handrails should be light in weight and they should permit a view through them while driving on the bridge. The handrails, parapets or posts should be designed to resist a lateral horizontal force and vertical force each of 1.50 kN per metre run applied simultaneously at the top of the railing or parapet.

Depending upon the site conditions, length of bridge, importance of bridge, etc., it is possible to find out various alternative designs for the handrails to a particular bridge. But in general, the handrails can broadly be grouped in the following *two* categories:

(1) Panel slab and post system

(2) Post and rail system.

(1) *Panel slab and post system:* In this system, the R.C.C. vertical posts are cast monolithic with kerb at a spacing of about 2000 mm and the space between adjacent posts is filled up by placing precast slabs having attractive pattern of holes or perforations.

(2) *Post and rail system:* In this system the vertical posts of R.C.C. or steel are spaced at about 2000 mm interval and space between the adjacent posts is filled up by rails of suitable sections. The struts may be provided to give rigidity to the handrail. It is possible to have different designs of rails or grillwork.

Following points should be noted in connection with the handrails to a bridge:

(1) *Approaches to a bridge:* If the approaches to a bridge are on a curve or on high embankments, it is desirable to provide handrails on both edges to such approaches to minimize the chances of accidents.

(2) *Culverts:* The simple solid parapet walls of adequate height, either in stone masonry or brick masonry, will be sufficient for the culverts and minor bridges to serve the purpose of handrail. The minimum height above the road surface should be 300 mm with a thickness of at least 200 mm.

(3) *Hill roads:* The parapets on hill roads may be made of dry stones with top course in mortar, about 600 mm high, in small lengths with gaps in–between.

(4) *Joints:* It is desirable to have joints in the handrails at about 8000 mm intervals. The double posts with a gap of about 12 mm between them are provided at the joints. The expansion gap of about 25 mm is provided over a pier between the handrails in the adjacent spans.

(5) *Kerb design:* The design of kerb is made in such a way that a vehicle after hitting a kerb is deflected to move parallel to the road and thus, the chances of vehicles falling from the bridge to the stream or river below are greatly reduced.

(6) *Submersible bridges:* The handrails to be provided for the causeways or submersible bridges should be of collapsible nature so that during floods, they will topple down and lie on the bridge floor. Such an arrangement results into minimum obstruction to the flow of water and floating debris during floods.

X. Joints:

The bridge joints should be designed in such a way that they require the least maintenance and they have good performance even with moderately high traffic of the present day. The joint is the weakest area of bridge and if not properly attended to, may lead to serious maintenance problems. The joints are of the following *two* types:

(1) Construction joints

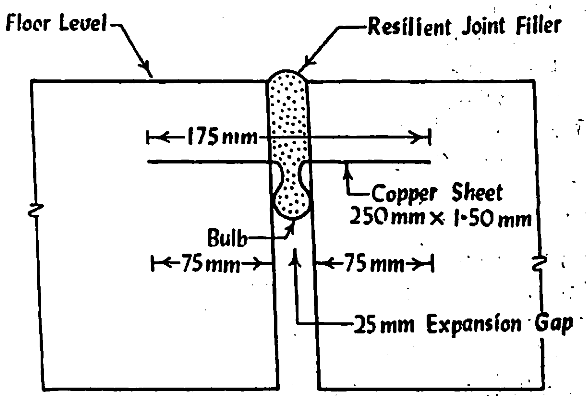
(2) Expansion and contraction joints.

(1) *Construction joints:* These joints are made between portions of the concrete constructed at different times due to the temporary suspension of the placement of concrete. Such a situation may be expected because of getting some facility in construction work or it may arise unexpected due to the reasons such as unfavourable weather condition, failure of machinery, etc. It also becomes necessary to provide the construction joint when the foundations of adjacent parts of the structure are at different levels as in case of junction between the abutment and wing wall.

(2) *Expansion and contraction joints:* These joints are provided to take care of deformations which take place due to changes in temperature. The expansion joints are for the full depth of the member. The contraction joints are usually of smaller width and they extend only upto the part of the depth of the slab, They are spaced closer than the expansion joints. As per the present practice, the expansion joints are provided at every pair of a simply supported structure and at the end of the girders in case of continuous and rigid frame bridges. Thus, the spacing of expansion joints will depend on the span length in case of a simply supported structure and the number of continuous spans in other cases.

The various types of expansion joints have been developed for accommodating the expansion ranging from 25 mm to 1800 mm.

Fig. 11–14 shows a typical expansion joint for a highway bridge with simply supported T–beam construction. The expansion gap is 25 mm and it is achieved by a copper sheet 1.5 mm thick and 250 mm wide bent in the form of a bulb in the middle portion so as to have an effective length of 175 mm. The gap above the copper plate is filled up with suitable resilient joint filler. This type of joint will allow expansion upto 22 mm. The other forms of expansion joints are mild steel angles and plates, finger plates, modular units, pre–fabricated modular compression seating system, etc.



Expansion joint
FIG. 11–14

It should be remembered that the number of expansion joints in the deck should be brought down to a minimum by arranging judiciously fixed and free bearings in a multi–span bridge.

Following are the *three* important requirements of an expansion joint:

(1) The sufficient space must be provided for accommodating smoothly the relative movements.

(2) The gap between the adjacent sides of the joint should be filled up or bridged in such a way that the riding over the joint is smooth and without jerks.

(3) The water must be prevented from entering and leaking through the joint.

XI. Maintenance of bridges:

After the bridge is constructed, it is absolutely necessary to inspect it at regular intervals and to maintain it in such condition that it functions properly. The damage to a bridge structure may be either due to faulty design or improper construction or due to the aging of the material. It may also occur due to external factors like floods, storms or accidents.

The defects which develop in any one particular component of a bridge structure can extend further slowly and ultimately, it becomes too weak to sustain the loads. If it is a vital member of the structure, it may fail causing total failure of the structure.

The details of inspection vary with the type of bridge and materials employed in its construction. The expectancy lives of substructure and superstructure are respectively as 100 years and 70 years. But the overall utility of a bridge can be drastically reduced due to faulty and poor maintenance. As the life of bridge is quite substantial, it is also likely that there can be a change in the traffic pattern and a bridge designed for lower loads may have to be subjected to higher loads.

Following are the general works of maintenance for the major bridges:

(1) Any signs of movement of the bricks or stones in masonry work should be carefully watched.

(2) The flood training bunds will have to be constructed and maintained in case of some rivers.

(3) It should be seen whether the masonry has washed, cracked or deteriorated. The cracks developed in the masonry will have to be examined carefully to see whether they are superficial or due to structural failure or defect.

(4) The suitable pitching is to be provided to the embankments near bridges.

(5) The bearings of girders should be coated with oil from time to time.

(6) The bed blocks should be inspected from time to time and the necessary repair should be immediately carried out.

(7) The floor system of approaches and bridges should be properly maintained.

(8) The movement of foundations, if any, should be carefully inspected and all attempts should be made to stop such further movement.

(9) The rivets should be carefully inspected at regular intervals and all defective rivets should be punched off and replaced.

(10) The soundings are to be taken in the river bed and depth of scour near the abutments and piers is to be detected.

(11) The superstructure of steel girder bridges should be periodically cleaned and painted with red lead at least once in 5 years. The steel requires constant attention because it is liable to corrode due to weathering action. If corrosion is not promptly attended, it will result in the section becoming unsafe.

(12) Due to fatigue some components of the steel structure may develop cracks. In a similar way, some members can buckle or can be bent due to overloading or accidents. The rivets of the joints tend to become loose due to the holes becoming oval. All such defects should be noticed during routine inspection and should be attended on a programmed basis.

(13) The concrete girders normally require very little maintenance except keeping them clean, examining for cracks that may develop and keeping the bearing area thoroughly free from dirt. Any crack of structural significance can be sealed by the pressure grouting or other means.

(14) The weep holes should be inspected regularly and they must be kept in working condition.

(15) In case of highway bridges, the condition of kerbs, parapet walls and footpath should be examined in all respects.

(16) The entire drainage system should be inspected for its proper functioning. The drainage spouts should be examined for any blockage, deterioration or damage. It is also sometimes found that the drained water is falling on a part of structure causing damage or acceleration of deteriorating effect on the same. The possibility of realigning or relocating such spots should be considered.

It is absolutely necessary that every part of the bridge structure is kept under constant observation. For this purpose, a periodic or routine inspection followed by detailed technical examination, wherever necessary, is essential. The technical inspection, should be entrusted to specially selected and trained personnel. Thus, the above–mentioned maintenance works can broadly be grouped into the following *two* categories:

(1) Detailed inspection
(2) Routine inspection.

(1) *Detailed Inspection:* The detailed or in–depth inspection involves the visual examination of all superstructure and substructure elements. It is carried out in the following *two* categories:

(i) *General:* A check–list of items is inspected either visually or with the aid of standard instruments in the general inspection. It is carried out once in 2 years.

(ii) *Major:* It requires close examination of elements with the aid of access facilities. It is conducted at intervals of 5 to 6 years or even at smaller intervals depending upon the design of the structure. The structural analysis of bridges is done by experienced bridge design engineers soon after the occurrence of calamities such as floods and earthquakes or the passage of high intensity loadings.

The trouble spots to be checked up during the detailed inspection are as follows:

(i) behaviour of expansion joints;
(ii) cracks in metalwork;
(iii) damaged structural members;
(iv) deterioration and cracks in concrete;
(v) excessive vibrations;
(vi) foundation settlement and movement;
(vii) indiscriminate past repairs;
(viii) inoperative expansion bearings;
(ix) loose connections; etc.

(2) *Routine Inspection:* The routine inspection aims to look after the general examination of structure at regular intervals and the spots having outward physical defects are immediately repaired. The routine inspection is generally applicable to short span bridges. The routine inspection is conducted prior to the monsoons and the data and details are recorded on a proforma. A post–monsoon inspection is also conducted in order to compare the data and check deterioration.

Following precautions should be taken during bridge maintenance:

(1) *Approaches:* The painted guard rails with suitable lights should be provided on the approaches to the bridges so that accidents due to poor visibility are avoided.

(2) *Bearings:* It is necessary to see that the bearings do not become inoperative because of poor maintenance.

(3) *Lights:* The bridges, especially in the urban areas, should be provided with attractive and delightful lights.

(4) *Surface dressing:* It should be checked that the periodic addition of surface dressing does not result into the increase in dead load far in excess of original load adopted in the bridge design.

XII. Posting of bridges:

The term posting of a bridge is used to mean the restriction on the use of bridge so as not to disturb its safe load carrying capacity. The posting of bridges can be classified in the following *two* categories:

(1) Load limit postings

(2) Speed postings.

(1) *Load limit postings:* The bridge is posted by the load limits and the load restriction may either be in the form of maximum axle loads or maximum gross loads of vehicles. The posting signs are in the form of advance warning signs and the load restriction signs and they are placed as under:

(i) The advanced warning signs indicating the load limit on bridge ahead, are placed about 200 m from the abutments on either side.

(ii) The load restriction signs, mentioning the load limit, are placed about 60 m from the abutments on either side.

(2) *Speed postings:* The restriction is put up on the speed of vehicles on the bridge. The speed postings reduce the impact effect and thus, the bridges can be allowed to carry heavier loads by reducing the speeds of vehicles. In general, the speed restrictions are not recommended and they should be resorted to only in the exceptional circumstances.

XIII. Rating of existing bridges:

The process of assessing the safe load carrying capacity is known as rating and it has to be systematically carried out for most of the existing old bridges which are not designed for the present day heavy highway loadings.

Following are the purposes of the rating of existing bridges:

(1) To afford safety to the traffic and public.

(2) To avoid immediate reconstruction of the existing bridges leading to substantial saving of money and materials of construction.

(3) To ensure smooth flow of traffic on the existing old bridges without imposing serious unnecessary restrictions.

(4) To suggest measures which would guarantee the safe use of existing bridges during the remaining period of their useful life.

During rating, the bridge is thoroughly inspected so as to determine its physical condition and the inspecting engineer must be well conversant with the design aspects as well as construction features of the bridge structures. The field inspections and investigations are properly recorded in the form of detailed sketches and self–explanatory notes. The findings are then correctly interpreted and suitable measures are recommended to remove the structural deficiency of the bridge.

The collection of field data after thorough inspection of the existing bridges is the most difficult part of rating and it should be entrusted to the experts only. In advanced countries like the U.S.A., the data processing and laborious calculations required for rating are made accurately with the help of computers and modern non–destructive testing equipments for giving in–depth information of a damaged member of the structure and which cannot be evaluated with the traditional tools during visual inspection. The commonly employed *three* such equipments are as follows:

(1) *Magnetic particle detector:* It is a portable magnetic equipment which is available for in–situ inspection. Its use is limited for the detection of surface or subsurface defects. The area of the metal to be inspected is magnetised and a fine magnetic powder is sprinkled on the surface under inspection. The layout of the powder formed is then analysed to detect the defect.

(2) *Radiographic equipment:* It employs X–rays or gamma rays to detect defects in the steel bridge structures. It requires a power source and cooling system in addition to the X–ray tube and film. This equipment is capable of detecting surface and subsurface defects. It provides a permanent record.

(3) *Ultrasonic testing equipment:* This is a simple portable equipment requiring a skilled operator. It is capable of locating both surface and subsurface defects in the metals including cracks, laminations, weld fusion, etc. It can also be used for measuring the plate thickness. It is well suited for analysing possible defects in the steel bridge elements and joints.

XIV. Rebuilding bridges:

An existing bridge in full or in part may be required to be rebuilt for one or more of the following *four* factors:

(1) Damage
(2) Excessive maintenance cost
(3) Obsolescence
(4) Weathering.

Each of the above factor will now be briefly described.

(1) *Damage:* The existing bridge might collapse or severely be damaged due to heavy unprecedented floods in the stream or river. Such floods can be caused due to various reasons such as breach in reservoir on upstream, increased precipitation of the catchment area, changed pattern of the flow of river, etc.

(2) *Excessive maintenance cost:* As the bridge approaches at the end of its service life, there is increase in its maintenance cost. Due to increased costs of labour and materials, it may happen that the maintenance cost including major repairs may become so excessive that it may prove economical to replace the existing bridge even though it has not completed its useful life.

(3) *Obsolescence:* The existing bridge may become functionally obsolete due to grade separation or change in the pattern of traffic or navigational requirements. The use of heavy and large locomotives or vehicles may be one of the main reason to replace the existing railway bridge.

(4) *Weathering:* Due to various weathering effects such as fumes, saline atmosphere, etc., there is deterioration of the bridge structure even though it is well maintained. The structural material can also be subjected to failure due to fatigue and in practice, it is extremely difficult to predict the actual fatigue service life of the structure. Hence, some members or parts of the structure may be subjected to more number of load cycles than expected and they may fail or give way far in advance of the intended service life of the bridge structure as a whole.

The replacement of the bridge structure may be done in part or in full depending upon the circumstances. The partial replacement is common in case of railway bridges whose substructure is of masonry and superstructure is of steel girders. The life of steel girders is normally less and the partial replacement is carried out using temporary arrangements and keeping the traffic moving continuously with restricted speed.

The entire bridge structure deserves to be replaced or rebuilt under the following circumstances:

(1) It has become too weak to take up the present day loads or traffic pattern.

(2) It has been considerably damaged due to corrosion of reinforcement, ageing, etc.

(3) It has become structurally overstressed due to hazards like floods, earthquake, falling of boulders, etc.

(4) It is not suitable due to faulty design and construction practices.

The most common forms of distress in bridge structures are;

(i) Corrosion of reinforcement;

(ii) Displacement of decks;

(iii) Flexural and shear cracks;

(iv) Movement of abutments;

(v) Sinking of wells;

(vi) Snapping of prestressing cables;

(vii) Tilting of piers; and

(viii) Topping of bearings.

Repair programmes frequently use one of the following specialised techniques:

(a) Epoxy resin injection;

(b) External prestressing;

(c) Externally bonded steel plates;

(d) Grouting, shotcreting.

The following repair scheme was adopted for rehabilitation of Ellis Bridge, Ahmedabad:

(1) Asphaltic concrete wearing coat W.B.M. and lime concrete were removed and corrugated plates were exposed.

(2) New plates were welded to the portion which were intact.

(3) Wherever corrosion had occurred, reinforcing plates were added.

(4) Reinforcement bars were placed over the cross girders for a width of about 1.5 m and cement concrete was cast to stiffen the deck.

(5) Sand blasting was done and then steel structure was painted with zinc rich epoxy and aluminium paint.

XV. Testing and strengthening of bridges:

After the construction work of a bridge is completed and before it is opened for traffic, it is necessary to test the bridge for its stiffness and strength.

The testing of bridge is usually carried out with the help of a deflectometer under various conditions of loading. The deflectometer records the deflection automatically and it is placed on the platform of instrument trestle. For taking readings of the instrument, an observation platform, which is entirely independent of the instrument platform, is constructed on another trestle.

The loads are allowed to stand, to move slowly and to run at maximum speed on the bridge. From the set of readings obtained, the strength and stiffness of bridge are computed.

The present day sudden explosion of heavy road traffic has posed the problem of testing and strengthening the existing bridges. It is quite clear that the weakest bridge on a particular route will be the deciding factor for the capacity of road or highway.

Following are the methods which are applied to work out the safe bearing capacity of an existing bridge:

(1) Correlation method

(2) Load testing

(3) Theoretical method.

Each of the above method will now be briefly discussed.

(1) *Correlation method:* The behaviour of another existing bridge with identical specifications and other similar details is studied and its safe bearing load is then correlated to the bridge under consideration.

(2) *Load testing:* The safe carrying capacity of the bridge is worked out by the application of loads. The tests with loads can either be proof tests or failure tests. The term proof tests is used to mean the tests in which loads exceed the usual working limits, but they do not cause any damage to the structure of the bridge as a whole. However, the proof tests are recommended only for simply supported

R.C.C. girder bridges and arch bridges because of the fact that in such cases, it is possible to conveniently associate the results with theoretical analysis. The term failure test indicates the application of loads which lead to the failure of bridge.

(3) *Theoretical method:* The relevant data pertaining to the bridge are collected and analysed theoretically. The safe load of the bridge can then be computed with the help of formulas, charts or tables.

If the results obtained during the testing of an existing bridge are not satisfactory, necessary structural repairs should be carried out so as to strengthen the bridge and thus prolong its useful period. The techniques to be adopted for the strengthening will naturally depend on the condition of the bridge, type of bridge, etc.

The various techniques to strengthen the bridge substructure and superstructure of different types of bridges will now be briefly mentioned.

Strengthening of bridge substructure: The bridge pier is usually of masonry or any other material and when it has been deteriorated, the strengthening can be carried out as follows:

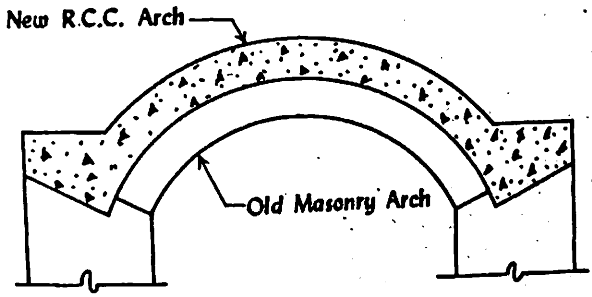
(1) *Masonry pier:* The loose material is scraped off and large cavities, if any, are filled up with the cement concrete. The surface is cleaned and a wire netting is fastened around the entire masonry with the help of spikes. The surface is then finally provided with a coat of cement mortar, preferably by using a gun.

(2) *Other material:* In this case, the cofferdam is constructed to enclose the space around the damaged pier and water is taken out. A thick cement concrete casing can then be provided or the old pier may be driven in the space between the old pier and the cofferdam to strengthen the foundation of the damaged pier.

Strengthening of bridge superstructure: The bridge superstructure is to be strengthened by keeping in mind the type of bridge to be handled. The strengthening techniques adopted for some of the common types of bridge superstructure are as follows:

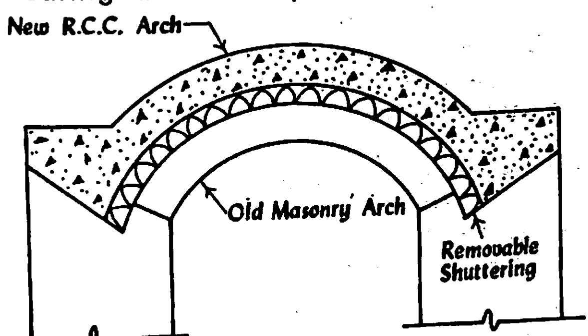
(1) *Continuous bridges:* These bridges are strengthened by methods similar to those of single span without any remarkable variation. But care must be taken to see that when a span is being strengthened, the adjacent span is not weakened.

(2) *Masonry arch bridges:* For masonry arches, the simplest way of strengthening is to remove the filling above the arch and cast an R.C.C. slab on top of the roughened extrados, effectively keyed into the abutments as shown in fig. 11–15. This method is adopted when the existing section is sound and can continue to contribute strength. The new R.C.C. arch serves as a supplementary section only.



Strengthening of masonry arch bridges
FIG. 11–15

When the existing arch is too weak to bear any load beyond its own weight, the new arch must be built several centimetres above the existing extrados with the help of removable shuttering as shown in fig. 11–16. The existing arch serves only the purpose of supporting the formwork during construction. The shuttering can be removed after casting and curing the new R.C.C. arch.



Strengthening of masonry arch bridges
FIG. 11–16

(3) *R.C.C. beam and slab bridges:* The beams are strengthened by means of steel I–beams on each side of the existing beams. For longer spans, the steel built–up girders support steel cross–girders spaced at intervals which take directly the load from the existing beams.

(4) *R.C.C. slab bridges:* The simplest way to strengthen an R.C.C. bridge is to place a slab on the top of the existing slab. The old surface is cleaned and by providing pockets or chases, a rough surface is formed. Then, a coat of cement slurry is spread before laying the new slab so as to ensure the fact that both the slabs act as monolithic.

(5) *Steel bridges:* These bridges are strengthened by the usual method of concrete encasement or the provision of extra steel plates or angles.

(6) *Suspension bridges:* These bridges are normally strengthened by the additional suspension requirements such as extra cables with fasteners.

XVI. Training works for bridges:

Objects: It is found that in most parts of our country, the rainfall is concentrated during a small period of about 3 to 4 months of monsoon only. The variation in river discharge is to the extent of about 50 to 100 times the normal discharge in the river. Under such conditions, the behaviour of rivers will be uncertain and hence, the main purpose of river training works is to stabilize the river channel along a well-defined alignment with a certain cross-section.

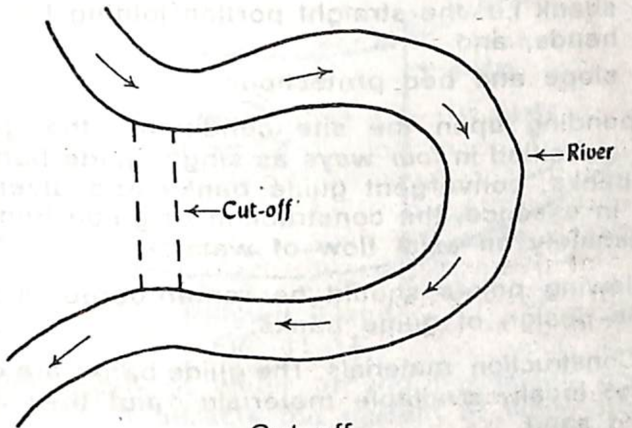
The other objects of the river training works can be mentioned as follows:

(1) To ensure minimum depth of flow of water for the navigation purposes.
(2) To grant protection to the approach embankments by deflecting the river and avoiding their erosion.
(3) To prevent flooding of the surrounding cultivated and inhabited lands.
(4) To prevent the river from changing its course and thereby to start flowing outside the constructed work.
(5) To provide the minimum width of river at the bridge site so that the construction of bridge can be carried out smoothly and economically.

Methods: Following are the commonly adopted *six* methods of the river training works:

(1) Cut-offs
(2) Embankments
(3) Guide banks
(4) Pitched islands
(5) Pitching of banks
(6) Spurs.

(1) *Cut–offs:* When the meandering of a river develops to extreme conditions, in the shape of a hair–pin bend, the land between the *two* portions of bend may gradually dwindle to a narrow neck which may easily be cut across by natural flood flow. This chord–channel connecting *two* portions of bend is called the natural cut–off as shown in fig. 11–17 and it may be made artificially to make the river flow straight. The cut–off reduces the length to be crossed. It thus shortens the distance for navigation and reclaims some useful land or property.



Cut–off

FIG. 11–17

(2) *Embankments:* They are constructed parallel to the river banks and upto a height of about 12 m. Depending upon the position of the embankments, they are classified in the following *two* categories:

(i) *Marginal embankments:* These embankments are constructed as close to the banks as possible so as to provide adequate waterway during the monsoon. They protect the marginal land from inundation caused by the floods. They are also referred to as the dykes and they are designed to retain water upto the maximum anticipated H.F.L. without the possibility of overtopping and with a view to resist all external pressures. They are also provided with necessary freeboard, bed width, top width and adequate slopes. The side slopes of these banks which are facing towards the river water are pitched with stones to bear the wave action of water.

(ii) *Retired embankments:* These embankments are constructed at a distance, usually on a lower ground, away from the river banks.

(3) *Guide banks:* The guide banks are used where a river is made to pass in a straight direction through a restricted waterway. The guide bank system of river training at bridges was first introduced by Mr. J. R. Bell and was subsequently perfected by Sir Francis Spring.

The guide bank essentially consists of the following *four* parts:

(i) upstream curved head,

(ii) downstream curved head,

(iii) shank i.e. the straight portion joining the *two* curved heads, and

(iv) slope and bed protections.

Depending upon the site conditions, the guide banks can be classified in *four* ways as single guide banks, parallel guide banks, convergent guide banks and divergent guide banks. In essence, the construction of guide banks ensures approximately an axial flow of water.

Following points should be remembered in connection with the design of guide banks:

(i) Construction materials: The guide banks are constructed from the locally available materials and they are usually made of sand.

(ii) Curvature at heads: The upstream curved head generally subtends an angle of about 120° to 145° to the centre of bridge and that of downstream head is about 45° to 90°. The radius of downstream curved head may be kept about one–half than that of the upstream curved head.

(iii) Design: The design of guide banks should be such that no spirals or eddies are formed.

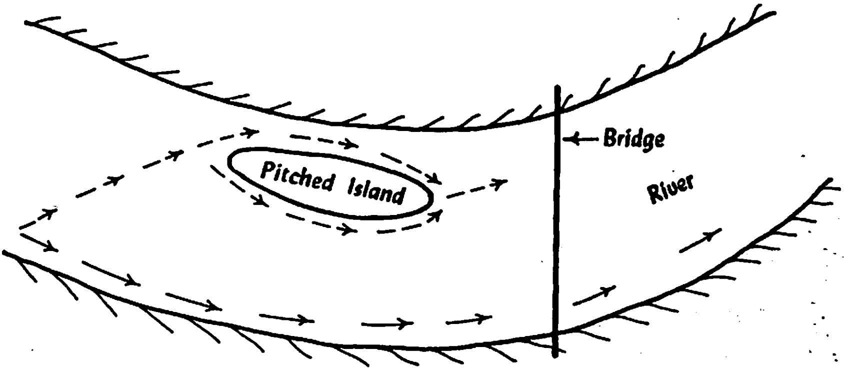
(iv) Length: The upstream length of guide bank should be equal to or 10 per cent longer than the length of the bridge between the abutments. The downstream length of guide bank should be one–fourth of the bridge length.

(v) Side slope: The side slopes are usually kept as 2:1 with a free board of 1250 mm to 1500 mm.

(vi) Site: The site for guide bank should be chosen in such a way that there is no side channel flowing parallel to the guide bank.

(vii) Top width: The top width of guide bank should not be less than 3000 mm.

(4) *Pitched islands:* A pitched island is an artificially constructed island in the river bed and it is protected by stone pitching on all sides. The use of pitched island is made when the river is flowing towards one bank only and it is desired to change the position of it. The island becomes an obstruction to the flow of water and it develops turbulence which starts scouring around the island and the river gradually becomes deeper around the island.



Pitched island
FIG. 11–18

When the depth of water around the island becomes sufficiently more, it attracts the current of water from the other side of the bank and thus, the concentration of the current at the other side bank is reduced as shown in fig. 11–18. The dotted arrows show the path of water flow after the construction of pitched island. The actual design details of pitched islands is usually carried out with the help of model studies.

(5) *Pitching of banks:* The river bank in the required length of river is cut to a stable uniform slope from 1:1 to 2:1 depending upon the material of the bank and then, the pitching or revetment is done with the help of boulders, concrete or brick blocks, brushwood, growing forest or the natural growth of grass. Thus, the river banks are made safe from the caving action of water. The bank revetment also exerts an attracting influence by drawing the river water towards it on account of deep scour formed at the toe of bank. The river channel is, in this way, held permanently at the pitched banks.

(6) *Spurs:* These are also referred to as the *groynes* or *transverse dykes* and they indicate structures, built transverse to the river flow, extending from the river bank towards the river. They serve the following purposes:

(1) They attract, deflect or repel the flow of water along a desired course.

(2) They contract the wide river channel.

(3) They form a pool of nearly still water along a particular bank.

(4) They give initial approximate straightness to the river before approaching the bridge site.

(5) They protect the bank from which they are projected by keeping the flow of water away from it.

(6) They restrict the side movement or meandering tendency of the river.

The success of river training by spurs depends mainly on the correct positioning and spacing of spurs and depending on the purpose they serve, they are classified in the following *three* categories:

(i) attracting spurs;
(ii) deflecting spurs; and
(iii) repelling spurs.

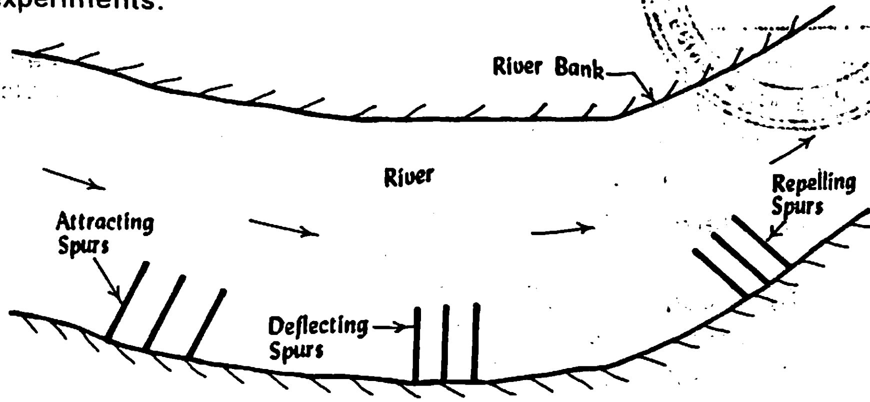
When a spur points downstream at an angle of about 45° to 60° with the river bank, it is called the *attractive spur* and it attracts the river flow towards the bank from which it is taken off. It thus makes the river adhere to a particular bank.

When a spur of short length is taken perpendicular to the river bank, it is known as the *deflecting spur* and it only deflects the flow locally.

When a spur points upstream at an angle of about 60° to 80° with the river bank, it is called the *repelling spur* because such a type of spur has the property of repelling the river flow away from the bank. Thus, the river bank on the side of repelling spurs is protected by the spurs from the erosive action of water. Also, the silt deposit takes place between repelling spurs and thus, it further strengthens the bank. Fig. 11–19 shows the attracting, deflecting and repelling spurs.

The spurs may be permeable or impermeable. The permeable spurs may be made of trees, bamboos, piles or matresses. They may be submerged or non–submerged. They are easily damaged by the floating debris. The impermeable spurs are built like embankments and they do not permit appreciable flow through them.

The length of spurs, their spacing and their inclination with the horizontal are decided suitably after the model experiments.



Spurs
FIG. 11-19

QUESTIONS

1. Define afflux and indicate its importance.
2. How is the height of afflux worked out? What precaution is to be taken during the measurement of afflux?
3. What are the approaches? Mention the important points to be remembered for the approaches of a bridge.
4. What are the aspects of bridge architecture?
5. What are the reasons for providing the vertical clearance in all categories of bridges? Mention the usual provisions for the same.
6. Explain with the help of neat sketches the various possible combinations of rail–cum–road bridges.
7. Define an economic span of a bridge and work out its expression.
8. What are the cases in which it is not possible to adopt an economic span?
9. Define the following:
   (1) Afflux
   (2) Approach road
   (3) Freeboard
   (4) Tellurometer
   (5) Economic span
   (6) Trestle centering
   (7) Proof tests.

10. Discuss the erection of steel girders.
11. What are the points to be remembered in connection with the design of guide banks?
12. What factors affect the type and design of centering for arch bridges? Mention good features of a typical design for the centering of arch bridges.
13. Write short notes on:
    (1) Merriman's formula for working out afflux
    (2) Rail–cum–road bridge on river Godavari
    (3) Erection of steel girders by staging
    (4) Steel truss centering for arches
    (5) Construction joints
    (6) Testing of bridges
    (7) Spurs
    (8) Embankments
    (9) Pitched islands.
14. Describe the various types of centering for arch bridges.
15. What are the precautions to be taken to make the timber truss centering successful for the arches?
16. Mention the advantages of trestle centering for the arches.
17. Why are the handrails necessary on the sides of a bridge? Describe the two categories of handrails.
18. Give sketches of the following:
    (1) Rail–cum–road bridge
    (2) Trestle centering
    (3) Expansion joint.
19. What are the important points to be noted in connection with the handrails to a bridge?
20. Explain the two types of bridge joints.
21. Enumerate maintenance works for a major bridge.
22. What are the trouble spots to be checked up during detailed inspection?
23. Mention the precautions to be taken during the bridge maintenance.
24. What are the methods which are employed to work out the safe bearing capacity of an existing bridge?

25. What are the three important requirements of an expansion joint?
26. What are the two categories of posting of bridges?
27. Write a critical note on the rating of existing bridges.
28. Why is an existing bridge required to be rebuilt?
29. When does the entire bridge structure deserve to be replaced or rebuilt?
30. Discuss the various techniques adopted to strengthen the bridge substructure and superstructure.
31. What are the objects of training works for bridges?
32. Describe the usual methods of river training works.
33. Differentiate between the following:
    (1) Freeboard and vertical clearance
    (2) Span and economic span
    (3) Floating and rolling methods of erection of steel girders
    (4) Expansion and construction joints
    (5) Detailed inspection and routing inspection
    (6) Marginal embankments and retired embankments
    (7) Attracting spurs and repelling spurs.
34. Give reasons for the following:
    (1) The greater the afflux, the greater will be the depth of foundations.
    (2) If the approach is in filling, it is to be seen that the borrow pits are not very near to the embankment.
    (3) Sometimes, the same bridge is used to carry the road as well as the railway.
    (4) There is some relation between the economic span and total height of the pier.
    (5) In some cases, the centering will be required for the erection of steel girders.
    (6) The handrails are necessary on the sides of a bridge.
    (7) The handrails to be provided for the causeways or submersible bridges should be of collapsible nature.
    (8) It is necessary to check the periodic addition of surface dressing on the bridge floor.

(9) The proof tests are recommended only for simply supported R.C.C. girder bridges and arch bridges.

(10) During rating, the bridge is thoroughly inspected.

(11) The bridge can be allowed to carry heavier loads when speed posting is adopted.

(12) The rating of the most of the existing old bridges should be carried out systematically.

(13) It becomes necessary to construct the river training works at the bridge site.

(14) The river channel is held permanently at the pitched banks.

(15) The approaches should be reasonably free from flood damages.

(16) The steel structures require constant attention.

(17) It is likely that the existing bridge may become functionally obsolete.

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