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GOVERNMENT OF INDIA

MINISTRY OF RAILWAYS

सत्यमेव जयते

GUIDELINES
ON
TYPE OF FOUNDATIONS FOR RAILWAY BRIDGES

REPORT NO. BS-127(R1)

JUNE – 2021

Issued by

BRIDGE & STRUCTURES DIRECTORATE

RESEARCH DESIGNS & STANDARDS ORGANISATION

MANAK NAGAR, LUCKNOW –226011

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FOREWORD

The Report outlines the type of foundations commonly used in Railway Bridges and ROBs, the factors influencing the selection of appropriate type of foundations and relevant insights into the subject. The contents should not be treated as prescriptive for selection of type of foundations in bridges which is a site specific techno-economic decision.

RDSO prepared "Guidelines on Type of Foundations for Railway Bridges" in form of BS Report, BS-127 in May 2019 subsequent to deliberations in 84th and 85th Bridge & Structures Standards Committee. The subject was further discussed in Video Conferences with Railway Board. Railway Board suggested reviewing of the Guideline.

Accordingly, the revised Guideline BS-127(R1) is being issued in supersession of BS-127.

14/06/2021

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Guidelines on Type of Foundations for Railway Bridges

1.0 Introduction

1.1 General

Foundation is an important structural part of a bridge. It is the lowest part of bridge structure which transfers all the loads falling over it to the ground. It distributes the loads over a large bearing area of soil/rock to provide stability of bridge against settlement and tilting. The loads transmitted by the foundation to the underlying soil must not cause failure of soil. The foundation should be of sufficient area, adequate depth, at appropriate level, not to cause shear failure & undue settlement of soil and not affected by the scouring. Suitable type of foundation should be designed only after ascertaining proper subsoil data of bridge site.

1.2 Requirement of foundations

Foundation should satisfy the following requirements:

a) The foundation must have an adequate depth to prevent undermining by scour.

b) The foundation must be safe against a bearing capacity failure.

c) The foundation must not settle to such an extent that it damages the structure.

d) The foundation must be of sufficient strength that it does not crush or break apart under the applied superstructure loads.

e) The foundation must be of design specifications.

f) The foundation must be able to resist long-term adverse soil changes like expansive soil, which could expand or shrink causing movement of the foundation and damage to the structure.

g) The foundation must be able to sustain the earthquake without significant damage.

1.3 Factors for consideration in foundations

Following factors should be considered before finalization of the type of foundation:

a) Design considerations i.e. transfer and distribution of the loads to the ground.

b) Type and condition of the soil or rock to which the foundation transfers the loads.

c) Safe bearing capacity of soil.

d) General layout of the pier/abutment showing the estimated axial & shear loads including moments and torques due to various loads coming on the foundation units.

e) Estimated depth of foundation.

f) Type of bed of stream.

g) Other conditions prevailing at proposed site like flooding, changes in ground water level, drainage, erosion, Railway Affecting Works (RAW) and chemical conditions of the sub-soil water etc.

h) Behaviour of the bridge, topography and environment/ surroundings, the type and depth of foundations and the bearing pressure adjacent to the site.

i) Seismic zone of the region.

1.4 Type of foundations

Broadly, there are two type of foundations mentioned as under:

1.4.1 Shallow (Open) foundations:

a) Isolated foundation

b) Raft foundation

c) Open foundation for bridges like pipe and box culverts

1.4.2 Deep foundations:

(i) Pile foundations:

a) Based on the manner of transfer of load:

- Friction piles
- Bearing piles
- Bearing-cum-friction piles

b) Based on construction methods:

- Driven Pre-cast piles
- Driven cast in-situ piles
- Bored cast-in-situ piles
- Precast concrete piles in pre bored holes
- Timber piles
- Spun piles (for deep marshy soils)

(ii) Well foundations:

- Circular
- Double-D
- Double octagonal
- Rectangular
- Twin circular
- Wells with multiple dredge holes

2.0 Factors affecting adoption of particular type of foundations

The selection of a particular type of foundation is based on a number of factors such as:

a) **Adequate depth-**The foundation must have an adequate depth to prevent undermining by scour.

b) **Bearing capacity failure-**The foundation must be safe against a bearing capacity failure.

c) **Settlement-**The foundation must not settle to such an extent that it damages the structure.

d) **Quality-**The foundation must be of adequate quality from safety and durability point of view.

e) **Adequate strength-**The foundation must be designed with sufficient strength that it does not fracture or break apart under the applied loads. The foundation must also be properly constructed in conformity with the design specifications.

f) **Adverse soil changes-**The foundation must be able to resist long-term adverse soil changes. An example is expansive soil, which could expand or shrink causing movement of the foundation and damage to the structure.

g) **Seismic force-**The foundation must be able to support the structure during an earthquake without excessive settlement or lateral movement.

Based on an analysis of all of the factors listed above, a specific type of foundation to be adopted based on **techno-economic justification**.

3.0 Suitability and Choice of foundations

a) The choice of type of foundation for the selected type of super structure and span arrangement has to be based on the sub-soil investigations and data of existing structures in the vicinity. The choice of foundation for Railway bridges depends on the site conditions also.

b) The choice of bridge foundation depends upon the importance of bridge, size and nature of soil and sub-soil in the bed and velocity of water flow.

c) The main criteria governing the choice of foundation for a structure comprise of:

(i) Function of bridge
(ii) Loads, the foundation will be required to support
(iii) Subsoil condition
(iv) Cost of the foundation in relation to the cost of the superstructure

d) Often the choice of the type of foundation is arrived at by the process of elimination. An experienced engineer first discards, almost instinctively, the most unsuitable types of foundation and concentrates on a few most promising ones. When the choice has been narrowed down to two or three, detailed analysis is made and their relative economy studied before arriving at the final decision.

e) On account of the interplay of many factors, there can be several acceptable solutions to a given foundation problem based on situation, experience, engineer judgment etc.

3.1 Shallow foundations

a) Shallow foundations are preferred where suitable hard strata which is not erodible and having adequate Safe Bearing Capacity (SBC) is available at shallow depth below bed level of the water course.

b) Shallow foundations are preferred as they are economical and easy to execute.

c) In rocky soil, it will be adequate if it is properly keyed into the rock for a minimum of 0.3 m in case of hard rock and 1.5 m in case of soft rock subject to the Codal provisions. Sloping rock may be suitably benched. Fissures and weathered rocks should be avoided.

d) In soft soils, rafts may be provided as foundation. Such rafts should be protected by means of suitable aprons and cut off walls or launching aprons, both on the upstream and downstream sides to prevent undermining of the foundations.

e) Open foundations, where feasible, are generally more economical than deep foundations if they do not have to be installed deep into the ground and extensive ground improvement works are not required. They are often used to support structures at sites where subsurface materials are sufficiently strong. Unless a shallow foundation is founded on strong rock, some noticeable settlement will occur.

f) Open foundation is suitable for bridges where rock or firm subsoil is available at shallow depth and there is not much scour and flowing water in the stream. (Ref. IRBM Para 316)

g) Open foundations must rest on a stratum with adequate bearing capacity. In order to reduce the bearing pressure the base can be sufficiently widened by providing footings. The footings will rest on a lean concrete bed of adequate thickness. The foundation should be taken to a depth not less than 1.75 meters below the lowest anticipated scoured bed level/original ground level in ordinary soil. (Ref. IRBM Para 403).

Shallow foundations are categorized into following types:

3.1.1 Isolated open foundations

Isolated open foundations are generally adopted where the Safe Bearing Capacity (SBC) of about 150 KN/m^2 or more is available at shallow depths. However, if sub soil is porous and water table is high this type of foundation would be generally feasible only upto 3 to 4m below the bed. (Ref. IRC SP: 82-2008)

3.1.2 Raft foundations

a) Foundation block covering the entire length and width of the proposed bridge structure is commonly known as raft foundation.

b) It is adopted when good founding strata is not available within reasonable depth or Safe Bearing Capacity (SBC) of top stratum is generally less than 100 KN/m^2.

c) In soft soils, rafts may be provided as foundation. Such rafts should be protected by means of suitable aprons and cut off walls or launching aprons, both on the upstream and downstream sides to prevent undermining of the foundations.(Ref. IRBM Para 403)

d) The concrete raft serves to distribute pressure evenly to the sandy surface/ clayey strata.

3.2 Deep foundations

a) Deep foundation become necessary when soil strata/ rock level is not available up to a depth of say 6 m or there is availability of substantial depth of water and large scour depth. (Ref. IRC SP:82-2008)

b) Uniform stable ground requires relatively shallow foundation whereas filled up ground has low bearing capacity and thus requires deep foundation.

c) For river bridges where discharge is high, i.e. more scouring of bed is expected and load on the sub-structure is too high to be carried by top soil layers, in such cases, execution of open foundation and the bed protection works become difficult and it is advisable to adopt deep foundation.

d) Deep foundation is more expensive, more complex, take more time to construct.

e) Deep foundations are used to transfer loads to a stronger layer, which may be located at a significant depth below the ground surface.

f) Cast-in-situ piles can be formed to any desired length. The length of driven piles normally does not exceed 25 to 30m depending on the capacity of driving equipment. (Ref. IRBM Para 408-4)

For more depths, well foundation should be adopted. Even in case of lesser depths (say less than 20m); an economic analysis should be done for adopting pile/ well foundation.

Deep foundations are categorized into following types:

3.2.1 Well foundations

a) Well foundation or caisson is one in which circular casings made of concrete or steel are sunk continuously one over another to reach larger depths when the soil at top is of less strength to hold the load from the structures.

b) This is one of the most popular type of deep foundations in India, due to various reasons like simplicity, requirements of very little equipment for execution and adaptability to different subsoil conditions/ difficult site conditions like deep standing water and availability of good founding strata at large depths etc. (Ref. IRC SP: 82-2008)

c) Well foundation provides a solid and massive foundation for heavy loads and large horizontal forces. This has a larger cross sectional area and hence the total foundation load carrying capacity is much higher. The well provides a very good grip when taken sufficiently deep and hence is most suited for river beds subjected to heavy scour.(Ref. IRBM Para 316)

d) Well foundation is suitable when heavy loads are applied on the bridge. Well foundation can be constructed through granular soil and in cohesive soil. The well may be of many shapes. The inside of well is filled with granular soil.

e) For bridges with single line, circular wells are adequate. The circular well is simple to construct, easy to sink and has uniform strength in all directions. It can be better controlled against tilt and shift. The only disadvantage is the limitation in size which restricts its use to bridges with smaller piers.

f) Where the pier length is larger as in the case of double line bridges, double-D wells may be used .The shape of Double-D well facilitates easy casting and sinking due to presence of two dredge holes. The overall length of the well generally is restricted to twice the width.

g) Wells can be taken through soil having boulders, logs of wood and such type of obstruction, without causing damage to the structure.

A typical section of well foundation is shown in Fig.1 (Ref. IRBM Para 316)

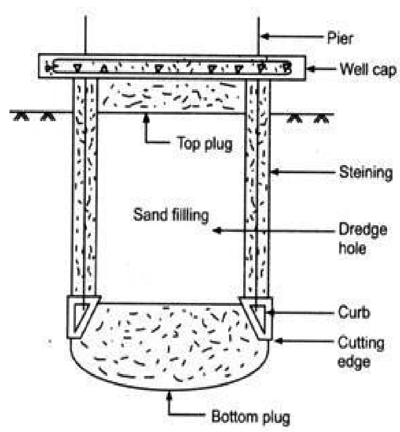


Fig.1 Typical section of well foundation

Wells are constructed in various shapes as under:

(i) Circular well

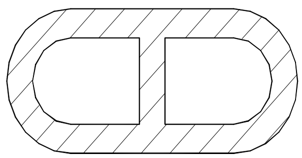
This type of well is most common due to its simplicity in construction and ease in sinking. It requires only one dredger for sinking and its weight per unit area of surface is the highest due to which the sinking effort for this well is also high. The distance of the cutting edge from the dredge hole is uniform all over and the chances of tilting are minimum in this type of well. The well is generally adopted for piers of single track railway bridges and those of bridges on narrow roads. When the piers are very long the size of circular well becomes unduly large, which makes them costly and disadvantageous hydraulically also as they cause excessive obstruction to the flow of water. Nine metre is generally considered as the maximum diameter of a circular well.

(ii) Double-D Well

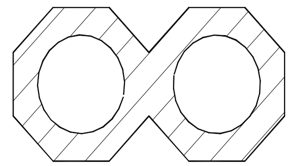
This type of well is most common for the piers and abutments of bridges which are too long to be accommodated on circular well. The shape is simple and it is easy to sink this type of well also. The dimensions of the well are so determined that the length and the width of the dredge holes are almost equal. It is also recommended by some engineers that the overall length of the well should not be more than double the width. The disadvantage of this type of well is that considerable bending moments are caused in the steining due to the difference in the earth pressure from outside and water pressure from inside which results in vertical cracks in the steining particularly in the straight portions at the joining of the partition wall.

(iii) Double Octagonal well

These types of wells are free from the shortcoming of double-D well. Blind corners are eliminated and bending stresses in the steining are also reduced considerably. They, however, offer greater resistance against sinking on account of the increased surface area. Masonry in steining is also more difficult than in case of double-D wells.



Double -D Well



Double Octagonal Well

3.2.2 Pile foundations

a) A pile is a vertical structural element of a deep foundation, driven or drilled deep into the ground. Broadly, piles transfer axial loads either substantially by friction along its shaft and/or by end bearing. Piles are used where either of the above load transfer mechanism is possible depending upon the sub-soil stratification at a particular site IRC: 78 may be referred for detailed information with regard to various types of pile foundations and their suitability. (Ref. IRC SP: 82-2008)

b) Piling should be considered when spread footings cannot be founded on rock, or on competent soils at a reasonable cost. At locations where soil conditions normally permit the use of spread footings but the potential exists for scour, liquefaction or lateral spreading, piles resting on suitable materials below susceptible soils should be considered.

c) Piles should also be considered where right-of-way or other space limitations do not allow the use of spread footings, or where existing soil is contaminated by hazardous materials and removal for construction of shallow foundations is not desirable.

d) Piles should also be considered where an unacceptable amount of settlement of spread footings may occur.

e) It is a foundation system that transfers loads to a deeper and adequately strong soil layer. The purpose of pile foundation is to reduce excessive settlement, prevent uplift forces where soil has inadequate bearing capacity at shallow depths.

f) It is a type of foundation that is used when the soil near the ground surface is weak.

g) Pile foundations are also viable alternative. Large diameter piles sometimes prove to be a good alternative to conventional well type foundations.

h) Pile foundation can be quiet economical, particularly where the foundations have to be built very deep or taken through deep layers of soil subjected to little scour. Larger diameter piles can be provided to take care of large horizontal forces when the foundations are deep. Larger diameter piles can also be provided for foundation depths beyond the limit of pneumatic operations. (Ref. IRBM Para 316)

i) In case of temporary bridge ,timber piles can be used as done in railways and roadways in the North-Eastern part of India in past.

j) Large diameter bored piles of more than one metre diameter are normally used for Railway bridge construction. (Ref. IRBM Para 407).

A typical section of pile foundations is shown in Fig.2 below:

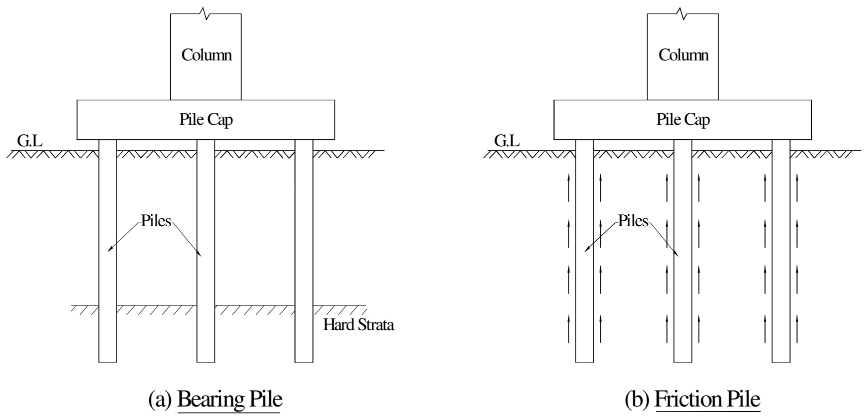


Fig. 2 Typical section of pile foundations

3.2.3 Comparison of Well and Pile foundations

a) Well foundations provide a solid and massive foundation for heavy loads as against a cluster of piles which are slender and weak individually and are liable to get damaged when hit by floating trees or boulders rolling on the river bed in case of bridge piers. Pile foundations are not suitable where liquefaction of soil is expected in case of seismic activity.

b) Wells have a large cross sectional area and the bearing capacity of soil for this area is much greater than that of the same soil at the same depth for end bearing piles of small cross section.

c) The size of well foundations cannot be reduced indefinitely as the dredge hole must be enough to enable a grab to work and the steining must have the thickness necessary to provide the required sinking effort. It is, therefore, not economical to use well foundations for smaller loads for which pile foundations are more suitable.

d) Wells are hollow at the centre and most of the material is at the periphery. This provides a large section modulus with the minimum cross sectional area. They can resist large horizontal forces and can also take vertical loads even when the unsupported length is large. The section modulus of individual piles in a cluster is small and they may not be economical for carrying large horizontal forces or vertical loads when the unsupported length is large as in case of bridge piers and abutments in scourable river beds.

e) In case of wells sunk by dewatering or pneumatic sinking, it is possible to visually examine the strata through which sinking is done in its natural state and the material on which they are finally founded. Even when sinking is done by dredging, the dredged material gives a fairly good idea of the strata through which the well is sunk. Drilled piles and caisson piles also have this advantage over the driven piles.

f) Masonry or concreting in the steining of wells is done under dry conditions and their quality is much better than in case of cast in situ piles for which concreting is done below the ground level and in many cases below the water level, where it cannot be inspected. Even in case of precast piles, the concrete is subjected to a lot of hammering and damage to it cannot be ruled out.

g) In case of wells, the raising of the well steining and sinking are done in stages and a decision about the foundation level can be taken as the work progresses and condition of strata becomes known. In case of precast piles, a decision about the depth has to be taken in advance. If the bearing capacity of the piles at the design depth is found to be less than the calculated value after testing, it may become necessary to redesign the foundation and the piles of short length already cast may have to be rejected or additional number of piles may have to be provided in each cluster. On the other hand if the stratum is too hard, it may not be possible to sink them to the design depth and the piles may have to be cut which is costly and wasteful. However, this does not apply to cast in situ piles.

In addition to above, choice between well and pile should be governed by sound Engineering practice, techno-economic considerations, and site requirement.

3.3 ROB foundations

Deep foundations are, in general, costlier as compared to the open foundation. The ROBs don't have water flowing around them, so scour is not a concern and the depth of foundation can be kept smaller also. If the soil conditions dictate or there is some other advantages like ease of construction, reduction in duration of caution order, we must go in for deep foundations like piles. If such constraints are not there, open foundations should be adopted, if feasible from bearing capacity considerations.

4.0 Conclusion

4.1 Shallow foundations are generally suitable where adequate safe bearing capacity is available at shallow depths, founding strata is non-erodible or can be protected against scour, at reasonable cost by suitably designed flooring protection works.

4.2 Pile foundations are generally suited where good founding strata is available below a large depth, construction in deep standing water, and where scour is moderate, etc.

4.3 Well foundations are considered more suitable in rivers with large scour and floating debris, where large horizontal forces are to be resisted, etc.

Choice of type of foundations for any bridge is site specific and depends on several parameters some of which are listed in the Para 1.3 and 2.0. Therefore, the decision has to be taken by engineers based on sound engineering practice, techno-economic considerations and site requirements such as type of sub-strata, quantum of loads to be supported, hydraulic and hydrological considerations, constructability, possibility of providing cost effective protection works etc.

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