PLANNING, SCHEDULING AND CONTROLLING

Dr. Shrishail B Anadinni
Nakul Ramanna Sanjeevaiah

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Regd. Office:
F-10/24, East Krishna Nagar, Near Vijay Chowk, Delhi-110051
Ph. No: +91-11-79669196, +91-9899073222
E-mail: info@booksarcade.co.in, booksarcade.pub@gmail.com
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CHAPTER - 1

INTRODUCTION TO G+5 STORY BUILDING

Dr. Shrishail B Anadinni, Professor and Associate Dean (Core Branches),
Department of Civil Engineering, Presidency University, Bangalore, Karnataka, India
Email Id- shrishail@presidencyuniversity.in

Extended Three-dimensional Analysis for Building Systems is known as ETABS. Skyscrapers, parking garages, steel and concrete structures, low and high rise buildings, including portal frame constructions are some of the structures that ETABS is often used to analyses. A powerful yet user-friendly special purpose analysis and design application created especially for building systems is called ETABS [1],[2]. Using a shared database, ETABS integrates unequalled modelling, analytical, and design techniques with a user-friendly and potent graphical interface. ETABS is the instrument of choice for structural engineers throughout the construction industry because, although being fast and simple for basic buildings, it can also manage the biggest and most complicated building models, including a broad spectrum of nonlinear behaviour. Buildings were identified as highly exceptional class structures more than 30 years ago, during the first development of ETABS, the forerunner of ETABS. Early ETABS versions included numerical solution approaches that considered input, output, and features specific to building types, resulting in a tool that was far faster than general-purpose applications and more accurate. With the advancement of computers and user interfaces, ETABS included computationally challenging analytical alternatives including dynamic nonlinear behaviour and potent drawing tools like to those found in CAD in a graphical and object-based user interface [3], [4]. The majority of structures have simple geometry, consisting of vertical columns, horizontal beams, and so on. With ETABS, any building arrangement is feasible, although in most circumstances, a simple grid system comprised of vertical column lines and horizontal floor lines may be used to quickly generate a structure's geometry [5].

Currently, open ground floors are a common feature of many multi-story buildings in India, whether they are being built for residential, commercial, institutional, commercial, or any other use. To give enough room for parking on the ground level or in lobbies, add architectural flair, and improve the floor space index, floating columns are necessary. The ground floor is often kept free of all structural components for parking purposes, with the exception of the columns that transfer the building's weight to the ground. buildings having vast interrupted sections essential for human activity or vehicle circulation on the lower levels, including event halls, lobbies, lecture rooms, and malls. High-rise structures both with and without columns were subjected to static analysis. By shifting the location of floating columns floor by floor, investigations into buildings with diverse instances were conducted. The displacement of column and base shear was studied in relation to the performance of building models. The research, which was carried out using SAP2000, discovered that the displacement of a building's individual stores with floating columns is greater than that of those without them. Examined the impact of seismic upheaval on a floating column in various soil environments. Two structures in seismic zone V with soft stores and uneven mass were examined to see how the floating column might affect them. The geometry, form, and scale of the structure all affect how it responds to an earthquake excitation. The shortest path must be used to convey the earthquake loads generated in a building's different floor heights down to the soil layers. Building dysfunction results from any interruption in the load-transferring route. A particular floor of a structure with fewer columns and walls is probably not good. Thus, the current research compares structural characteristics including horizontal displacement, storey drift, and storey shear during seismic excitation and assesses the reaction of a structure with G+5 stores with and without floating columns.

Engineering that deals with both the construction of buildings like homes is known as building construction. A simple structure is one that has walls, a roof, supplies for food and clothing, and other necessities for human habitation. To shelter themselves against wild animals, rain, sun, and other elements throughout the early parts of human history, people lived in caves, above trees, or under trees. As time went on, people began to dwell in huts constructed of wood branches. The ancient shelters have been transformed now into lovely homes. Homes exist in a wide variety of forms and functions and have historically been designed for a wide range of factors, including the availability of construction materials, climatic conditions, land prices, floor conditions, specific uses, and aesthetic considerations [6]. A form with many floors within in the tower above level is referred to as a multi-storey building. The goal of multi-story houses is to increase the building's floor space without increasing the land area on which the building is erected, saving land and, in most cases, money (depending on the material employed and the area's land values). The multi-shop building design method requires not only creativity and conceptual thinking, but also a strong understanding of structural engineering scientific knowledge as well as knowledge of practical elements, such as current design codes and bye laws, supported by extensive experience, instinct, and judgement. The objectives of the standards are to maintain and improve safety while also carefully balancing economy and safety. Therefore, reducing the thickness of the floor and drop panels will lessen the amount of concrete in a safe manner. For contemporary architecture, the flat slab offers both structural stability with aesthetic appeal.

Floating Column

A column is a vertical structural part that extends from of the base level that transfers force to the soil layers. It is a vertical structural element that terminates on a horizontal member, such as a beam. As depicted in Figure 1, the floating column distributes the weight to the beams, which then transmit the energy to certain other columns.

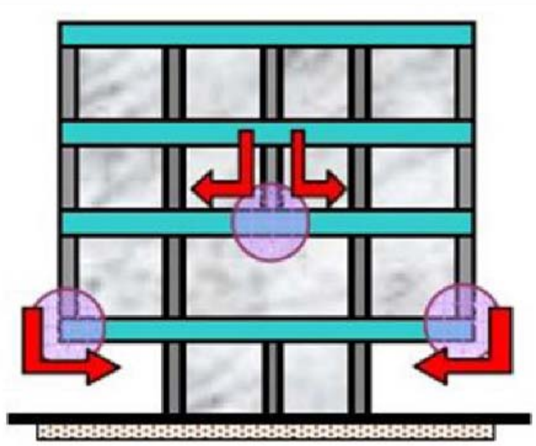

Figure 1: Illustrates the floating column transfers the load to the beams and these beams transmit the force to other columns [3]**.**

Bibliography

[1] R. Taherkhani and A. L. Saleh, "Awareness and prevalence of Industrialized Building System (IBS) in Iran," *J. Teknol.*, 2019, doi: 10.11113/jt.v81.13364.

[2] G. Pradeep, P. Chandra Shaker, and S. V. S. Prasad, "Building management system," *Int. J. Innov. Technol. Explor. Eng.*, 2019, doi: 10.35940/ijitee.K2161.0981119.

[3] S. K. Singh, S. Priya, M. Nadeem, and M. B. Alam, "Analysis of G+5 Storeys Building With and Without Floating Column," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 889, no. 1, p. 012008, Nov. 2021, doi: 10.1088/1755-1315/889/1/012008.

[4] P. Tamang and G. Prasad Sharma, "Comparison between seismic performance of G+5 building with and without Fluid Viscous Dampers," in *IOP Conference Series: Earth and Environmental Science*, 2021. doi: 10.1088/1755-1315/796/1/012003.

[5] S. Navaratnam, T. Ngo, T. Gunawardena, and D. Henderson, "Performance review of prefabricated building systems and future research in Australia," *Buildings*. 2019. doi: 10.3390/buildings9020038.

[6] I. L. Jabar, A. R. Abdul-Aziz, S. Suresh, S. Renukappa, and A. Enshassi, "A project management competency framework for industrialised building system (IBS) construction," *Int. J. Technol.*, 2019, doi: 10.14716/ijtech.v10i4.2773.

CHAPTER - 2

BASIC PRINCIPLES OF STOREY BUILDINGS

Ms. Anju Mathew, Assistant Professor,
Department of Civil Engineering, Presidency University, Bangalore, Karnataka, India
Email Id- anjumathew@presidencyuniversity.in

Although software is often utilised to create an effective design, it is still crucial for an engineer who's really new to constructing single-story structures to comprehend how the structure acts and how its many parts work together [1]. The major frames' logical sequence is defined using eight stages. The design of the reinforcing, gables, secondary steelwork, and cladding come next [2], [3]. There are included general guidelines to assist the designer in rapidly and effectively coming up with a solution that is appropriate for a certain set of limitations.

Basic Principles of Good Design

The simplicity, length of time, and cost of fabricating and constructing a steel-framed structure may all be significantly influenced by a few fundamental decisions [4],[5]. The following guidelines should be followed:

- The optimal solution will result from keeping fabrication and installation in mind from the beginning.
- Maintain a straightforward and well-known design (avoid using novel methods unless they are justifiable).
- It may not be ideal to weigh the least.
- Standardize wherever you can.
- Be mindful of interfaces.

Anatomy of a portal framed building

The vast majority of single storey buildings in the UK are portal framed buildings. These were first widely used in the 1960s. During the 1970s and early 1980s they developed rapidly to become the predominant form of single storey construction. A portal framed building comprises a series of unbraced transverse frames, braced longitudinally. The primary steelwork consists of columns and rafters, which form the portal frames, and longitudinal bracing. The end frame (gable frame) can be either a portal frame or a braced arrangement of columns and rafters. The figures below show the principle building components of a portal frame building. The secondary steelwork which supports the cladding consists of side rails for walls and purlins for the roof. The secondary steelwork also plays an important role in restraining the primary steelwork members against buckling out-of-plane. The roof and wall cladding separate the enclosed space from the external environment and provide thermal and acoustic insulation. The cladding transfers loads to the secondary steelwork and restrains the flange of the purlin or rail to which it is attached. A number of options are available for each of these parts of a portal framed building [6].

Interface

The interaction between the main steel frame as well as the building envelope, through the secondary steelwork, demands special consideration for single-story structures. This is such that both the secondary steelwork and the envelope may serve several purposes (as noted above). These components may be specified by several designers, thus it is crucial to communicate design assumptions clearly. Additionally, it is essential that designers and erectors communicate.

Portal Frame

Typically low-rise buildings, portal frames are made up of columns and horizontal or pitched rafters that are joined together by moment-resisting connections. The rigidity of the interconnections as well as the bending stiffness of a members, which is augmented by an appropriate haunch or depth of the rafter sections, give resistance against lateral and vertical motions. This kind of continuous frame construction has a clean span that is unhindered by bracing and is robust in its plane. In fact, 50% of the construction steel employed in the UK is utilised to make portal frames, making them quite prevalent. They are frequently used for industrial, storage, retail, and commercial applications in addition to agricultural uses since they are particularly effective at enclosing enormous quantities. The anatomy, multiple portal frame types, and important design factors are all covered in this page. The most typical kind of building construction is a portal steel frame building. Light steel structures like garages, workshops, sheds, and warehouses often employ it. The solid web or lattice portal frame, which serves as the primary load-bearing structure, is made of welded H-shaped (equal or varied cross-section) steel, hot-rolled H-shaped steel, or cold-formed thin-walled metal. Corrugated metal sheeting are utilised for roofs and walls, and cold-formed thin-wall steel (C or Z-shaped) is used for purlins and wall girt. Other materials for heat conservation including heat insulation include stiff polyurethane foam, rock wool, mineral wool, fiber glass, and others.

Form of Rigid Frame

The portal frame construction may take many different forms, including single-span, double-span, high-low-span, including multi-span, as well as single, double, multiple, plus flat slopes as well as ridges and slopes. Single-span rigid frameworks are often employed in structures with little need for lateral space. The typical span is 18–36 metres. H-shaped sections are frequently utilised, whether welded or rolled. The bending distances diagram and span are used to calculate the location and elevation of variable-section columns and beams. Large buildings may benefit from the multi-span rigid frame, which has a cross-section comparable to a single-span rigid frame but often uses an equal cross-section for the central column. The portal frame's greatest span has now reached 72 metres.

Factors of Portal Steel Frame Buildings that consider in the design

Dead load

The portal steel frame structures' self-weight is generated by the design programme. According to the actual design, a load for the roof, purlins, bracing, and other loads applied to the steel frame were computed. Sandwich panels and perforated single-color sheets may be used as roof or wall panels, respectively. The sandwich panel's insulating components include polyurethane, glass wool, mineral wool, polystyrene foam, and others. The design should use certain materials to ascertain the wall and roof loads.

Variable load

Live roofs, ash, cranes, seismic activity, wind, etc. are examples of variable loads. The roof's live load must not exceed 0.5 kN/M2, according to the "Design Requirements for Portal Steel Frame Light Steel Structures" (CECS102: 2002). The reduction factor may increase by 0.6 if indeed the load area is greater than 60M2. Therefore, the standard steel frame calculation employs 0.3 kN/m2.

Minimize the amount of steel

The main steel frame and the purlin account for even more than 90% of the steel consumption in portal steel frame structures. Additionally, the column spacing configuration considerably affects steel consumption when the same load circumstances. According to many statistical studies, the optimal column spacing is 6 to 8 metres, and the appropriate span is 36 metres. Purlins should also be made of thin-walled C and Z-type steel, whereas H-shaped sections are often used for steel frames.

Bibliography

[1] A. Kaiser, M. Larsson, and U. A. Girhammar, "From file to factory: Innovative design solutions for multi-storey timber buildings applied to project Zembla in Kalmar, Sweden," *Front. Archit. Res.*, 2019, doi: 10.1016/j.foar.2018.12.001.

[2] E. O. Adebisi, S. O. Ojo, and O. O. Alao, "Assessment of factors influencing the failure and abandonment of multi-storey building projects in Nigeria," *Int. J. Build. Pathol. Adapt.*, 2018, doi: 10.1108/IJBPA-10-2017-0048.

[3] S. Omrani, V. Garcia-Hansen, B. Capra, and R. Drogemuller, "Natural ventilation in multi-storey buildings: Design process and review of evaluation tools," *Building and Environment*. 2017. doi: 10.1016/j.buildenv.2017.02.012.

[4] E. Markström, M. Kitek Kuzman, A. Bystedt, and D. Sandberg, "Use of wood products in multi-storey residential buildings: views of Swedish actors and suggested measures for an increased use," *Wood Mater. Sci. Eng.*, 2019, doi: 10.1080/17480272.2019.1600164.

[5] M. Badaoui, N. Bourahla, and M. Bensaibi, "Estimation of accidental eccentricities for multi-storey buildings using artificial neural networks," *Asian J. Civ. Eng.*, 2019, doi: 10.1007/s42107-019-00137-x.

[6] H. S. Structure, "Portal Steel Frame Buildings," 2020. https://havitsteelstructure.com/specification-of-portal-steel-frame-buildings/ (accessed Dec. 26, 2022).

CHAPTER - 3

PORTAL FRAME STRUCTURE

Mr. Dayalan J, Assistant Professor,
Department of Civil Engineering, Presidency University, Bangalore, Karnataka, India
Email Id- dayalanj@presidencyuniversity.in

Numerous frames that are only supported in the axial direction and not in the transverse direction make up a portal frame construction. Each frame of the building is made up of several columns and rafters [1],[2]. On its top, there is bracing throughout the frames between two successive portal frames [1], [3]. The steel component is also included in portal frames [4]. They are made comprised of roof purlins and side rails which support the outside wall. These steel components are necessary because they play a crucial part in preventing the portal frames' buckling, which comprise the main steel constructions. The components of a portal frame are shown in Figure 1 as follows:

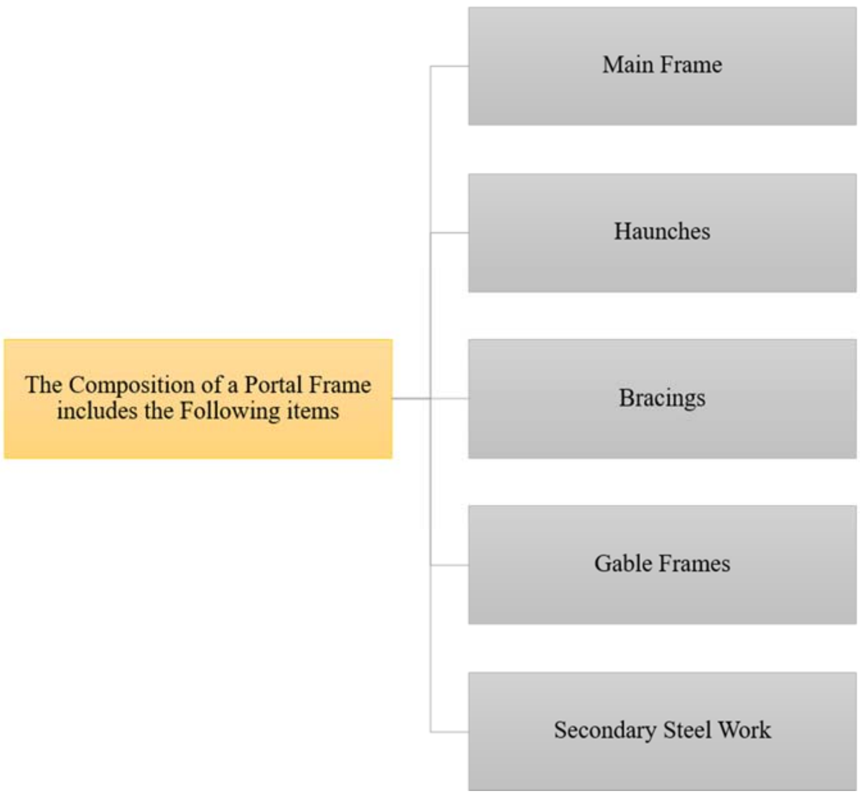

Figure 1: Illustrates the Composition of a Portal Frame.

Types of Portal Frames

Based on their intended function and other classifications, a wide variety of portal frame designs may be created. A framed building may be categorized as having symmetrical or asymmetrical portal frames. It may also be categorized into the following other kinds, which are listed:

Portal frame featuring a mezzanine floor

Office space is often located within such a steel portal frame construction that makes use of a mezzanine level. SCI P292 offers guidelines on how to show the impact of the mezzanine level in the evaluation of frame stability.

Pitched roof symmetric portal frame

The big eaves haunch piece is often cut from a manufactured plate or rolled section, and these frameworks are typically constructed from UB sections. The most practical and typical spans are 25 to 35 m [5].

Crane portal frame with column brackets

The crane rails may be supported by brackets that can be fastened to the frame's columns in the event that a travelling crane up to 20 tonnes is needed. This lessens the eaves deflection by employing a tie member or stiff column base. For the crane to operate as intended, the spreading of a frame there at crane's level is crucial. Prior to construction, specifications should indeed be agreed upon with the customer and approved by the crane manufacturer as well.

Tied portal frame

Both the bending movements in the columns and the horizontal displacement of the eaves found in a connected portal frame are greatly reduced. When it comes to preventing a crane-supported structure from spreading, tie portal frames may be quite useful. The usage of second-order software should indeed be required to analyses the frame's overall shape due to the strong axial forces that are created when a tie is applied.

Mono-pitch portal frame

Due to their closeness to nearby structures and limited spans, mono-pitch portal frames are often employed. These frames, which are a simple variant of the pitched roof entrance frame, are often suited for smaller projects with a span of up to 15 metres.

Propped portal frame

A propped portal frame was appropriate when the span of a portal frame is greater than typical and you are not required to give a clear span. This lessens the rafters' size and the horizontal shear that is present at the foundation level.

Mansard portal frame

Mansard portal frames are often used for big, clear-height mid-spans whenever a building's eaves height is kept to a minimum.

Curved rafter portal frame

Curved rafters, which are often used for architectural purposes, may be used to build portal frames. However, rafters longer than 20m frequently need splices because to transit restrictions [6]. SCI P281 provides information on the stability for curved rafters inside these types of portal frames. Curved members are typically represented for analysis was based on a succession of straight components. A sequence of straight rafters may also be used to create curved rafters as an alternative. Purlin cleats of varying heights must, however, be supplied in order to obtain a curved profile again for rafters while doing this.

Cellular beam portal frame

Cellular beams may be used to create rafter frames, and this is often done for aesthetic reasons. They could, however, be chosen in cases of lengthy distances and restricted transportation, which necessitates the usage of splices. They must to be fluid in form and meticulously crafted to maintain its architectural elements.

Bibliography

[1] M. V. M. Varanis, A. G. Mereles, A. L. Silva, J. M. Balthazar, A. M. Tusset, and C. Oliveira, "Modeling and experimental validation of two adjacent portal frame structures subjected to vibro-impact," *Lat. Am. J. Solids Struct.*, 2019, doi: 10.1590/1679-78255435.

[2] H. Suntoko, E. R. Iswanto, A. Marwanto, and A. M. Puteraka, "Design of Reinforced Concrete Shear Wall of Reactor Building, Experimental Power Reactor," in *Journal of Physics: Conference Series*, 2019. doi: 10.1088/1742-6596/1198/2/022057.

[3] M. J. Roberts, J. M. Davies, and Y. C. Wang, "Numerical analysis of a clad portal frame structure tested to destruction," *Structures*, 2021, doi: 10.1016/j.istruc.2021.06.098.

[4] H. B. Blum and K. J. R. Rasmussen, "Experimental investigation of long-span cold-formed steel double channel portal frames," *J. Constr. Steel Res.*, 2019, doi: 10.1016/j.jcsr.2018.11.020.

[5] S. Gram, "Types of Portal Frame Buildings," 2020. https://www.steelgram.co.uk/steel-portal-frame-buildings/what-is-a-portal-frame-building/ (accessed Dec. 26, 2022).

[6] J. Fabriciuss and L. Ozola, "Behaviour of timber portal frame depending on rotational stiffness of knee joint," in *Research for Rural Development*, 2019. doi: 10.22616/rrd.25.2019.025.

CHAPTER - 4

CONSIDERATIONS IN DESIGN

Ms. Anju Mathew, Assistant Professor,
Department of Civil Engineering, Presidency University, Bangalore, Karnataka, India
Email Id- anjumathew@presidencyuniversity.in

In the planning and building of any structure, it is essential to take into account a vast number of interconnected design criteria. The goal of this overview of a design process as well as its components aims to give the designer a clear grasp of the link between both the structural components and the finished structure so that choices can be made based on that understanding at each level [1].

Section and material choice

S355 steel sections are often used to construct portal frame constructions [2],[3]. Class 1 plastic sections must be employed at hinge places that rotate in plastic portal frames, whereas Class 2 compact parts may be used elsewhere.

Dimensions of the Frame

The height and breadth of the frame are essential during the conceptual design phase to provide enough interior dimensions and clearances for the building's activities [4].

Dimensions of the clear span and height

Early in the design phase, dimensions should be decided upon depending on the client's desired clear span and height. The open space between the flanges of both the two columns will probably be needed by the customer. As a result, the section depth would cause the span to be bigger. It should be decided if masonry or blockwork is required around the columns since it may have an impact on the design span. Clear interior heights are typically calculated from the completed floor level towards the bottom of the suspended or ham hock ceiling.

Main Frame

The main (portal) frames are typically constructed from UB pieces with a sizable eaves haunch portion that is either rolled or fashioned from plate. Typical frame characteristics include: stretches from 15 to 50 meters.

The haunch's clear height should range from 5 to 12 meters. Roof pitches range from 5° to 10°, however 6° is the most typical. Frames are spaced 6 to 8 meters apart. At the cornice and apex, there are haunches between the rafters. The diameter of the column and the portion of the rafter have a stiffness ratio of around 1.5. Side rails and purlins of light gauge. Light gauge diagonal ties are used to hold the inner flange of the frame in place at certain positions between some purlins as well as the side rails.

Dimensions of the haunch

A haunch's proportions are crucial depending on where it is utilised. By enhancing the member's moment resistances wherever applied moments are strongest, a haunch will lower the depth of the any rafter that is necessary [5], [6]. The haunch will also increase the portal frame's rigidity, reducing any deflections, and it will make it easier to create a solid bolted moment connection. Usually, the same-sized rolled segment of the rafter is made into eaves haunchers. It may alternatively be taken from a somewhat larger one. It is cut to length, bonded to the bottom of a rafter, and typically accounts for 10% of a frame's overall span. The biggest sagging moment there at apex, which is also the hogging moment, is used to determine the length of a haunch. 2% of the entire span is represented by its depth from the rafter axis to the bottom of the haunches. An apex haunch may be manufactured from plate or it could be cut straight from a rolled piece that is exactly the same size as the rafter. The apex haunch is solely needed to provide a bolted connection inside the frame and is often not modelled as component of the frame analysis.

Restraint Positioning

The rafter members are chosen at the original design phase based on their cross-sectional susceptibility to bending moments with axial force. Stability in respect to buckling should indeed be confirmed throughout the later design stages, and restrictions should be placed wisely. Because there is often significantly less flexibility in arranging the rails to coincide with the needs of the design, choosing the column size has a significant impact on buckling resistance. This implies that any windows and doors positioned in elevation may determine where the rails are placed. Buckling resistance first dictates the choice of sectional size when intermediate lateral restrictions are imposed and it is not practicable owing to the columns. Because of this, it's critical to decide early about whether side rails should have been utilised to confine the columns. The only kind that may effectively provide such constraints is continuous side rails. For example, side rails which have been broken by shutter doors shouldn't be depended upon since they don't provide enough restriction. An additional method of restraint is to use a column and rafter that remain on the inner flange when the compression flange, rafter, or columns isn't restrained utilizing purlins and side rails.

Actions

BS EN 1991 contains instructions on how to behave. A combination of activities are also specified in BS EN 1990. To start building these structures in the U.K., it is crucial that you employ the UK National Annex again for required Eurocode section.

Permanent Actions

Permanent actions pertain to the structure's own weight, any additional steelwork, but also external classification. It is important to take into account and collect the unit weights of every material used in building from the manufacturer's data. In the event that information cannot be discovered, BS EN 1991-1-1 contains this information.

Service Loads

Depending on how a building will be used, service loads will always vary. Any portal frame may be subject to significant point loads from the usage of elevated constructions like suspended walkways. Therefore, it's important to carefully assess any areas where further provisions could be needed. Depending on the building's intended use and if sprinklers must be installed during construction, it is typical to account for just a load of 0.1-0.25 kN/m2 on the roof's whole surface.

Imposed roof loads

The U.K. NA to BS EN 1991-1-1 accounts for any imposed loads which are put on roofs. It will, however, be determined by the roof slope itself. In order to locally inspect the roof fixings and components, a point load, Qi, is provided. This weight should be supplied vertically and distributed evenly. Keep in mind that imposed loads upon roofs should never include both wind and snow.

Bibliography

[1] S. Gram, "Types of Portal Frame Buildings," 2020. https://www.steelgram.co.uk/steel-portal-frame-buildings/what-is-a-portal-frame-building/ (accessed Dec. 26, 2022).

[2] A. M. Kaynia, "Seismic considerations in design of offshore wind turbines," *Soil Dyn. Earthq. Eng.*, 2019, doi: 10.1016/j.soildyn.2018.04.038.

[3] B. Stahre Wästberg, T. Eriksson, G. Karlsson, M. Sunnerstam, M. Axelsson, and M. Billger, "Design considerations for virtual laboratories: A comparative study of two virtual laboratories for learning about gas solubility and colour appearance," *Educ. Inf. Technol.*, 2019, doi: 10.1007/s10639-018-09857-0.

[4] A. Schieben, M. Wilbrink, C. Kettwich, R. Madigan, T. Louw, and N. Merat, "Designing the interaction of automated vehicles with other traffic participants: design considerations based on human needs and expectations," *Cogn. Technol. Work*, 2019, doi: 10.1007/s10111-018-0521-z.

[5] G. Zhang, L. H. Xu, and Z. X. Li, "Theoretical and parametric studies of a self-centering modular steel structure connection," *Eng. Struct.*, 2021, doi: 10.1016/j.engstruct.2021.113146.

[6] Y. Liu and Y. Wang, "Seismic performance experimental research on haunch connection of steel frame," *World Earthq. Eng.*, 2016.

CHAPTER - 5

COMPONENT OF STORES BUILDING

Dr. Nakul Ramanna Sanjeevaiah, Professor and Head,
Department of Civil Engineering, Presidency University, Bangalore, Karnataka, India
Email Id- nakul@presidencyuniversity.in

Snow Loads

Sometimes the major gravity loading may be identified using snow loads. The value of a snow load must be determined utilizing BS EN 1991-1-3 and its U.K. National Annex. It is also essential to use Page number of the Steel Designers' Manual to precisely calculate a snow load. Both the design of a frame itself and the design of a purlins, whose support the roof covering, must account for any drift situation [1],[2]. The fundamental minimum snow load will typically not be met due to the intensity of the loading and the location of the maximum drift [3].

Wind Action

Wind action measurement is essential, and it may be done by consulting BS EN 1991-1-4 and its U.K. National Annex. The Eurocode's appendix is a crucial document that will provide plenty of room for any necessary revisions. Wind activity is always intricate and will undoubtedly have an impact on any building's ultimate design. Therefore, while evaluating wind activities and selecting effective means of streamlining a design process, the designer must make a thoughtful decision. This also has to include cautious load bearing [4], [5].

Crane Actions

The most often used crane for any kind of building construction is indeed an overhead crane that would be supported by columns and operates on beams. Cantilever brackets or dual columns are used to support beams when they are heavier than average. A designer must take the effects of acceleration into account considering the weight of a cranes as well as any additional loads. When using basic cranes, amplified loads may be employed in conjunction with a quasi-static strategy.

Uses of Portal Frames

In a structure, portal frames are typically employed to create spacious areas. Such frames may be utilised for agricultural reasons in addition to being used for commercial and industrial storage. Depending on their needs and purposes, numerous types of materials may be used to build this frame. Without any bracing from the accessible spaces, portal frames are excellent for covering huge areas. Large expanses may be provided by such frames since they can be built to span up to 20 to 60 metres.

Advantages of Portal Frames in the Structure

The buildings' portal frames have various benefits, and they provide a low-cost design framework. When the surrounding area of the structure is vast, it is considerably more beneficial. Large areas may be produced with the least amount of resources by employing framed constructions. Other benefits are also present, and these are shown in Figure 1. Therefore, it may be built off-site in the event of such constructions, but if sufficient care is not taken into mind during planning, the buckling issue develops owing to its simplicity.

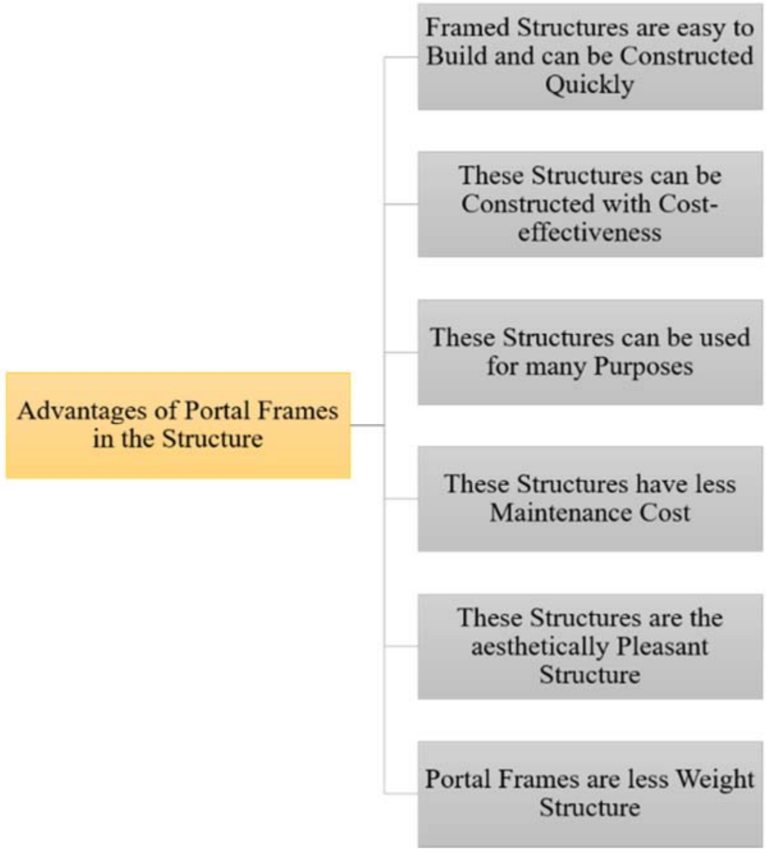

Figure 1: Illustrates the Advantages of Portal Frames in the Structure.

Properties of Building Material

In the current technological era, construction or building materials are indeed a need. There are many different kinds of building materials that are utilised for various construction projects. A material must possess the necessary technical features to be used in construction projects in order to be termed a building material. These characteristics of construction materials determine their quality and capability and aid in the selection of their intended uses. These characteristics of construction materials fall under the following categories. Physical characteristics Physical characteristics include mechanical, chemical, electrical, magnetic, and thermal ones.

Physical Properties of Building Materials

These are necessary characteristics to anticipate a material's quality and condition without the need of any outside forces. The following are the physical characteristics of engineering materials. Weight Density Porosity Durability Density Rank Particular Gravity Resistance to Fire Frost Resistance to weathering Sensitivity Resistance to spalling Water Solubility Water Absorption Moisture-Specificity Coefficient of Refractoriness and Softness.

Bulk Density of Building Materials

Bulk density is the mass-to-volume ratio of a material in its unprocessed condition, which includes voids and pores. It is stated as kg/m3. Strength, heat conductivity, as well as other mechanical qualities of materials are influenced by bulk density. Table 1 lists a few of the engineering materials' bulk specific gravity.

Table 1: Illustrates the bulk density values of some of the engineering materials [6]**.**

Building material	**Bulk density (kg/m3)**
Brick	1600 - 1800
Sand	1450 - 1650
Steel	7850
Heavy concrete Light concrete	1800 – 2500 500 - 1800
Granite	2500 – 2700

Bibliography

[1] A. C. Santos, B. Çakmak, S. Campbell, and N. T. Zinner, "Stable adiabatic quantum batteries," *Phys. Rev. E*, 2019, doi: 10.1103/PhysRevE.100.032107.

[2] U. Vitiello, V. Ciotta, A. Salzano, D. Asprone, G. Manfredi, and E. Cosenza, "BIM-based approach for the cost-optimization of seismic retrofit strategies on existing buildings," *Autom. Constr.*, 2019, doi: 10.1016/j.autcon.2018.10.023.

[3] M. T. Plytaria, C. Tzivanidis, E. Bellos, I. Alexopoulos, and K. A. Antonopoulos, "Thermal behavior of a building with incorporated phase change materials in the South and the North Wall," *Computation*, 2019, doi: 10.3390/computation7010002.

[4] A. Amiri, J. Ottelin, J. Sorvari, and S. Junnila, "Cities as carbon sinks - Classification of wooden buildings," *Environ. Res. Lett.*, 2020, doi: 10.1088/1748-9326/aba134.

[5] H. T. T. Le, V. Likhitruangsilp, and N. Yabuki, "A bim-database-integrated system for construction cost estimation," *ASEAN Eng. J.*, 2021, doi: 10.11113/AEJ.V11.16666.

[6] Construtor, "Properties of Building Materials," 2020. https://theconstructor.org/building/properties-of-building-materials-construction/14891/ (accessed Dec. 26, 2022).

CHAPTER - 6

POROSITY OF BUILDING MATERIALS

Mr. Dayalan J, Assistant Professor,
Department of Civil Engineering, Presidency University, Bangalore, Karnataka, India
Email Id- dayalanj@presidencyuniversity.in

The amount of space filled by pores in a substance is known as porosity. It is the proportion of pore volume to material volume [1], [2]. Numerous characteristics, including heat conductivity, strength, maximum dry density, and durability, are influenced by porosity.

Durability of Building Materials

Durability of material is the capacity of a substance to survive the combined action of environmental and other conditions [3],[4]. Longer life will be beneficial if the material is more resilient. Durability affects how much a material will cost to maintain.

Density of Building Materials

The ratio of a material's mass towards its volume in a homogeneous condition is known as its density [5]. The density values of the material have an impact on almost every one of its physical characteristics. Table 1 lists the density values of several construction materials.

Table 1: Illustrates the Density values of some building materials.

Material	Density (kg/m3)
Steel	7800 – 7900
Brick	2500 -2800
Granite	2600 – 2900

Density Index

Density index is the ratio of a material's bulk density towards its density. As a result, it provides the material's volume containing solid matter. Since totally dense materials are not found in nature, all construction materials in Figure 1 have a density index that is less than 1.

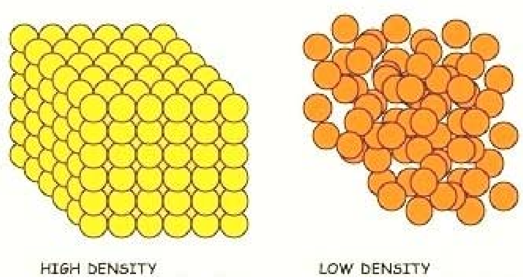

Figure 1: Illustrates the molecules of high density and low density [6]**.**

Mechanical Properties of Building Materials

By applying external forces on materials, mechanical characteristics may be discovered. These are highly significant characteristics that determine how a material performs in its function. Strength, hardness, elastic, plasticity, fracture toughness, fatigue, impact strength, resistance to abrasion, and creep are indeed the mechanical qualities.

Strength of Building Materials

Strength is the ability of a material to withstand failure brought on by loads operating on it. The load might be bending, tensile, or compressive. It is calculated by dividing the ultimate load that the material can bear by the area of its cross section. For every building material, strength is a crucial quality.

Therefore, factors of safety are supplied for materials and are chosen based on the nature of the task, the quality of the material, economic circumstances, etc., in order to ensure the greatest level of safety in strength.

Hardness of Building Materials

The capacity of a substance to withstand being scratched by a herd body. The MOHS scale is being used to assess a material's hardness. The use of a given aggregate depends mostly on its hardness. It also affects how well it works.

Elasticity of Building Materials

Elasticity is the property of a material that allows it to return to its original form and size after being relieved of a load.

Ideal elastic materials adhere to Hooke's law, which states that stress and strain are directly proportionate. Which expresses elastic modulus as the proportion of one unit of tension to one unit of displacement. The deformations are less when the modulus of elasticity is higher.

Plasticity

When a load is given to a material, if the material deforms permanently without breaking and maintains its shape whenever the load is removed, the material is considered to be plastic and this quality is referred to as plasticity. They provide resistance to bending, impact, and other forces. Examples include steel and hot bitumen.

Brittleness

If a material collapses under stress abruptly without deforming in any way, it is said to be brittle, and this characteristic is known as brittleness. Examples include cast iron and concrete.

Fatigue

Repetitive loads lead a material to fail at a position that is lower than the failure point brought on by constant loads. We call this behavioral weariness.

Impact Strength

The impact strength of a material is determined by how much deformation it experiences under abrupt loads without rupturing. It indicates how durable a substance is.

Abrasion Resistance

Abrasion is the term for material loss caused by particles rubbing against one another while operating. A material's ability to withstand abrasion makes it strong and long-lasting.

Creep

The long-term deformation brought on by persistent loads. It moves extremely slowly and is time-dependent. In typical circumstances, it is almost nonexistent. But when temperatures are high, conditions creep quickly.

Bibliography

[1] T. S. Freitas, A. S. Guimarães, S. Roels, V. P. de Freitas, and A. Cataldo, "Is the time-domain reflectometry (TDR) technique suitable for moisture content measurement in low-porosity building materials?," *Sustain.*, 2020, doi: 10.3390/SU12197855.

[2] T. P. Santos, M. Fátima Vaz, M. L. Pinto, and A. P. Carvalho, "Porosity characterization of old Portuguese ceramic tiles," *Constr. Build. Mater.*, 2012, doi: 10.1016/j.conbuildmat.2011.08.004.

[3] X. Guan *et al.*, "Chemically stable polyarylether-based covalent organic frameworks," *Nat. Chem.*, 2019, doi: 10.1038/s41557-019-0238-5.

[4] S. J. Lyle, P. J. Waller, and O. M. Yaghi, "Covalent Organic Frameworks: Organic Chemistry Extended into Two and Three Dimensions," *Trends in Chemistry*. 2019. doi: 10.1016/j.trechm.2019.03.001.

[5] S. Ali Akbar Razavi and A. Morsali, "Linker functionalized metal-organic frameworks," *Coordination Chemistry Reviews*. 2019. doi: 10.1016/j.ccr.2019.213023.

[6] Construtor, "Properties of Building Materials," 2020. https://theconstructor.org/building/properties-of-building-materials-construction/14891/ (accessed Dec. 26, 2022).

CHAPTER - 7

INTRODUCTION TO UNDERPASS ROAD BRIDGE

Dr. Nakul Ramanna Sanjeevaiah, Professor and Head,
Department of Civil Engineering, Presidency University, Bangalore, Karnataka, India.
Email Id:-nakul@presidencyuniversity.in

After being seldom employed in bridge building, the Underpass RCC Bridge has gained popularity for moving traffic. They are sometimes designed to enable animals to cross the street. Connecting two well-known national parks, Kanha and Pench (NH44), it is India's first underpass constructed exclusively for wildlife and makes a substantial contribution to the long-term sustainability of tiger populations in the vicinity of central India [1],[2]. Modern highway systems, especially urban interchanges, are increasingly using box type bridges because of their effective distribution of backed-up traffic, their economic advantages, and their aesthetic appeal [3]. The constructions known as underpasses are used to move animals, transportation, and water. It is necessary to provide a means of movement from one side to the other when there is a junction of two roads, one of which has considerable traffic. For the purpose of directing and regulating traffic, the Underpass RCC Bridge is utilised in bridge building. Such a bridge requires less area to build since there is less land available in cities. Since space or land are limited, building an underpass bridge is a preferable solution [4], [5]. The hydraulic jack mechanism is used to drive this RCC Bridge into the embankment. Such a bridge requires less area to build since there is less land available in the city. Rarely is the Underpass RCC Bridge utilised in bridge building, but lately it has been put to use for traffic flow. Using a hydraulic jack mechanism, this underpass RCC Bridge is pushed inside the embankment. A bridge of this sort requires less area to build since there is less land available in cities. Therefore, when there is a space or land restriction, building an underpass bridge is a superior alternative. The underpass RCC Bridge hasn't yet undergone a thorough examination or design [6].

Major infrastructure projects are large-scale, durable, expensive, and need the participation of many individuals with different levels of competence to complete. They are meant to meet current social requirements or to further societal progress. When confronted with the necessity to build and run significant infrastructure, the technical community must make a number of difficult choices. The steps of the process include design, solicitation, construction, maintenance, and management. The people engaged in realising each step must overcome environmental, societal, political, financial, legal, and technological obstacles. Each building project goes through a number of phases as it develops. The planning and design phase, which starts with the basic research and is followed by many design phases, is the first step in the complete method. The execution of the design with the real building is the most expensive phase. The operation and maintenance phase is the next longest and least taken into account in original cost projections. Therefore, reliable cost estimates are required at every step of a building project and are based on different data. Before the project's precise plans and specifications are established, preliminary cost estimates—also known as pre-design cost estimates, feasibility estimates, or screening estimates—are created. A rough cost projection is based only on the project's conceptual design and employs just the most fundamental technology. Unfortunately, awarding, completing, and evaluating the whole final design of a project before seeking money for its execution is not at all cost- or time-efficient at the beginning of a project. As a consequence, important players in the building process, such as project owners, designers, contractors, and financing agencies, often utilise the preliminary estimated costs based on the little information that is currently available. The adoption of proper funding techniques, cost-benefit analysis, feasibility studies, preliminary budgeting, comparison and financial assessment of competing projects, and many other decision-making processes all make use of these early cost estimates. For large-scale transportation infrastructure projects, which have historically shown significant cost overruns that, in most situations, range from 50% to 100%.

Rarely is indeed the Underpass RCC Bridge utilised in bridge building, but lately it has been put to use for traffic flow. This essay conducts a study of the RCC Bridge underpass. This RCC underpass bridge's study takes fixed end conditions into account. Results of an analysis using the finite element method (FEM) are provided. For fixed end conditions, a comparison of various forces comparing 2D and 3D models is given. In this research, we demonstrate that a 2D model may be utilised to analyses all of the loading conditions specified in IRC: 6, "Standard Specifications and Code of Practice Road Bridges," in an efficient manner. "Code of practice for the design of substructures and foundation of bridges" by the Indian Roads Congress and the Directorate of Bridges & Structures (2004) Standard for Indian Railways. Highway traffic has significantly increased over the last several decades as a result of population expansion and increasing urbanization. Numerous additional motorways and flyovers have indeed been constructed to maintain traffic flow. The building of bridges is now seen as being important on a global scale since it is a component of the contemporary world. It allows you to go around obstacles without blocking the way below. Conventional bridges are no longer necessary due to recent technology breakthroughs. Conventional bridges have been replaced with creative and economical structural methods. Modern highway systems, especially urban interchanges, are increasingly using box type bridges because of their effective distribution of backed-up traffic, their economic advantages, and overall aesthetic appeal. The constructions offer several benefits that are advantageous in the building of motorways and bridges, including structural effectiveness and serviceability.

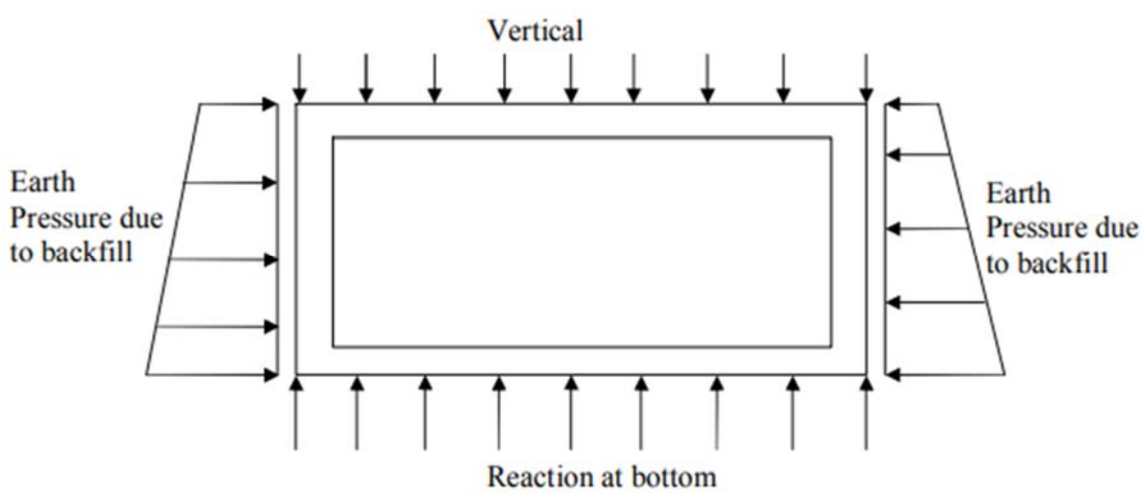

Figure1: Illustrates the 2D Model of RCC Underpass Bridge.

Modeling of System

Earth pressure from the embedded configuration of the Underpass RCC Bridge, as well as vertical loading from impact loading as well as live loads from the Overpass RCC Bridge are taken into consideration. These loads are specified in the "Procedural or administrative the loads for developing the super- structure and sub-structure of bridges and for determining the strength of existing bridges" (Indian Railway Benchmark code). Given that there is top loading, there is also bottom response. Additionally available for city traffic is this RCC underpass bridge. Figure 1 considers the live load from IRC: 62000 inside the underpass RCC Bridges for that reason.

Bibliography

[1] Y. Fujino, D. M. Siringoringo, Y. Ikeda, T. Nagayama, and T. Mizutani, "Research and Implementations of Structural Monitoring for Bridges and Buildings in Japan," *Engineering*. 2019. doi: 10.1016/j.eng.2019.09.006.

[2] P. G. Svensson and R. Loat, "Bridge-building for social transformation in sport for development and peace," *J. Sport Manag.*, 2019, doi: 10.1123/JSM.2018-0258.

[3] J. Koyama and S. Desjardin, "Building bridges and borders with deficit thinking," *Educ. Real.*, 2019, doi: 10.1590/2175-623686415.

[4] M. Bhardwaj, K. Soanes, T. M. Straka, J. J. Lahoz-Monfort, L. F. Lumsden, and R. van der Ree, "Differential use of highway underpasses by bats," *Biol. Conserv.*, 2017, doi: 10.1016/j.biocon.2017.05.022.

[5] P. Medrano-Vizcaíno and S. Espinosa, "Geography of roadkills within the Tropical Andes Biodiversity Hotspot: Poorly known vertebrates are part of the toll," *Biotropica*, 2021, doi: 10.1111/btp.12938.

[6] D. V. Krishna and A. Bjagadish Chakravarthy, "Rcc Underpass Design , Modeling and Analysis Using Parametric Study of Soil Structure Interactions," *Int. J. Adv. Res. IJOAR .org*, 2015.

CHAPTER - 8

HISTORY OF BRIDGE DEVELOPMENT

Dr. Shrishail B Anadinni, Professor and Associate Dean (Core Branches),
Department of Civil Engineering, Presidency University, Bangalore, Karnataka, India.
Email Id: - shrishail@presidencyuniversity.in

A bridge is not a physical structure; rather, it is a notion that refers to bridging vast expanses of land or sea in order to link distant locations and gradually shorten the distance between them. The bridge offers access across a physical barrier, such as a road, valley, body of water, or tiny tunnels. Bridge designs differ according on the kind of terrain, the bridge's purpose, and the location where it is built [1],[2]. The simplest bridges, such as a log that has fallen over a stream, were thought to have been created by nature [3]. Using a straightforward support and crossbeam structure, the first bridges constructed by humans were presumably spans composed of wooden logs or planks that were later replaced by stones. The mythical narratives of the bridges built from India to Sri Lanka either by army of Sri Rama, the legendary King of Ayodhya, are found in the Indian epic literary Ramayana. This bridge, which is mentioned in the Ramayana, is visible in a recent satellite image. In Kautilya's "Arthasastra," he mentions the Mauryan dynasty building bridges in India. In India, the Mughals built several bridges across significant rivers throughout their battles. Before making even the most basic shelters for themselves, prehistoric humans built bridges across waterways. The bridges were trees that had fallen over the creek from bank to bank. The earliest bridge builders were a nomadic tribe that made a tree purposefully fall over a waterway. As a result of seeing monkeys hang from various vines, parallel wires were connected with some kind of crosspieces to serve as bridge supports. After hand grips were discovered, suspension bridges were created. The Inca culture developed rope bridges, a basic kind of suspension bridge, in the Andes Mountains of South America [1], [4]. The earliest bridges were made naturally from enormous rock arches that reach. The first man-made structures were flat stones, girder-style tree trunks stretched over waterways, and icicle lights of vegetation that had been twisted or braided and suspended.

The roots of the truss, cantilever, cable-stayed, tied-arch, and movable spans were developed by engineers and builders from the three forms of beam, arch, and suspension, which have been recognised and constructed since antiquity. In various locations across India, tangled vine and creeper bridges were discovered. Some of the first bridges were made of wood. As early as 206 BC, suspension bridges were already well-known in China. The oldest stone bridge still standing in China is indeed the Zhaozhou Bridge, which was erected in the Sui Dynasty about 605 AD. The Chinese also built large wooden bridges before switching to stone building. The fact that this bridge is the oldest open-stone segmental arch bridge in the whole globe adds to its historical significance. The finest bridge builders in antiquity were the Romans. To lessen the difference in strength inherent in natural stone, they employed cement, or pozzolana, which is made of water, limestone, sand, and volcanic rock. Although incredibly adaptable, wood has one obvious drawback. During the 18th century, there were many innovations in bridge design, but the construction of the Iron Bridge in Coalbrookdale, England, in 1779, which used cast iron for the very first time as arches to cross the Severn River, marked a significant advancement in the field.

Wrought iron was replaced with steel, because of its high tensile strength, during the Industrial Revolution to build bigger bridges that could carry heavy weights. Later, welded structural bridges with different designs were built. Beam bridges, Cantilever bridges, Arch bridges, Suspension bridges, Cable stayed bridges, and Truss bridges are among the several types of bridges.

Beam Bridge

The framework of a beam bridge is indeed a horizontal beam anchored at both ends. The most straightforward sort of bridge to build is a beam bridge. Cantilever horizontal beams with just one end supported are used to construct cantilever bridges. The majority of cantilever bridges consist of two cantilever arms that meet in the middle and extend from each side of the barrier to be crossed. The Arch Bridge features supports at each of its ends and is designed like an arch. An arch-shaped bridge's weight is driven into its end supports. Cables hang from the suspension bridge. Both ends of the bridge include anchor points for the suspension cables. The strain in the cables is a direct result of the weight that the bridge is carrying. Cable remained Cables support some types of bridges, such suspension bridges. A cable-stayed bridge, on the other hand, uses proportionally less cable and has shorter towers supporting the cables. The Sutong Bridge across the Yangtze in China is the largest cable-stayed bridge in the world. Pin joints are used to connect the straight pieces that make up truss bridges. They feature a sturdy deck and a lattice of girders for the sidewalls that are pin-jointed or gusset-joined. Modern truss bridges were entirely built of metals like wrought iron and steel, or sometimes concrete structures, as opposed to the early truss bridges that were made of wood and subsequently of wood containing iron tension rods.

Build a Bridge

Try to build a model bridge after visiting numerous bridges in your nation and surfing online to look at various styles. Draw the design first. Choose your material next (s). Balsa wood, different kinds of wood, threads, toothpicks, straws, and even aluminium foil are often used by builders. Building a bridge model according to your ideas and imagination is enjoyable. You may colour your model if necessary.

Bridge

A bridge is a vertically loaded, horizontally spanning structure that connects two supports. The prototypical bridge is very straightforward, consisting of two supports proudly displaying a beam, but there are still inherent engineering challenges with every bridge: the maintains must be sturdy enough to support the structure, and the span between the supports must be sturdy enough to carry the loads. Spans are often kept as small as possible; lengthy spans are only acceptable in situations when there are few options for adequate foundations, such as across estuaries containing deep water. The public's funds are used to build all significant bridges. Therefore, the most effective bridge design has three objectives: to be as effective, inexpensive, and aesthetic as is safely feasible [5]. Efficiency is a scientific concept that values using fewer resources while getting more done. Economy is a societal ideal that values efficiency while lowering building and maintenance expenses. Finally, elegance is indeed a symbolic or aesthetic approach that prioritizes the designer's unique perspective without sacrificing efficiency or effectiveness. While there is minimal controversy about what efficiency and economy are, there has never been consensus on what beauty is. Since the early 19th century, modern designers have discussed elegance or aesthetics in their writings, starting with the Scottish engineer Thomas Telford. The public, who finally decides this matter, owns bridges, although generally speaking, experts choose one of three viewpoints. The first principle asserts that an engineer is responsible for a bridge's construction and that only the introduction of architecture can completely realize a bridge's beauty. The second concept maintains that bridges that use materials in the most effective way are by necessity beautiful. It does this by reasoning from the perspective of pure engineering. The third argument is that although design is not required, engineers must consider how to make the building attractive. This last concept acknowledges that engineers may express their own aesthetic views without considerably increasing material or expense since they have a wide range of options that are about equivalent in efficiency and economy [6].

Bibliography

[1] X. Zhou and X. Zhang, "Thoughts on the Development of Bridge Technology in China," *Engineering*. 2019. doi: 10.1016/j.eng.2019.10.001.

[2] C. Wan *et al.*, "Development of a bridge management system based on the building information modeling technology," *Sustain.*, 2019, doi: 10.3390/su11174583.

[3] X. Zheng, D. H. Yang, T. H. Yi, and H. N. Li, "Development of bridge influence line identification methods based on direct measurement data: A comprehensive review and comparison," *Engineering Structures*. 2019. doi: 10.1016/j.engstruct.2019.109539.

[4] A. Law and V. Atkinson, "Positive youth development: A bridge to connect civic education and sustainable development," *J. Youth Dev.*, 2021, doi: 10.5195/JYD.2021.1027.

[5] H. Liu, S. Leng, C. He, J. Peng, S. Piao, and X. Wang, "China's road towards sustainable development: Geography bridges science and solution," *Prog. Phys. Geogr.*, 2019, doi: 10.1177/0309133319851026.

[6] P. N. Billington, "Bridge," 2020. https://www.britannica.com/technology/bridge-engineering (accessed Dec. 26, 2022).

CHAPTER - 9

ELEMENTS OF BRIDGE DESIGN

Dr. Nakul Ramanna Sanjeevaiah, Professor and Head,
Department of Civil Engineering, Presidency University, Bangalore, Karnataka, India.
Email Id:-nakul@presidencyuniversity.in

There are six basic bridge forms: the beam, the truss, the arch, the suspension, the cantilever, and the cable-stay.

Beam Bridge

Beam was once a solid plank of wood that was used to build houses, ploughs, looms, and balances. A beam is a horizontal part used in building construction that spans an opening and supports a weight, such as a brick or stone wall just above entrance, in which case the beam is sometimes referred to as a corbel (see post-and-lintel system) [1],[2]. The beam is known as a floor joist or a ceiling joist depending on whether the weight is a building's floor or roof. In a bridge deck, the floor beams are indeed the heavier transverse elements while the stringers are the less laden longitudinal beams [3]. Girders are typically large beams that support the ends of many other beams perpendicular towards them. To allow for higher rigidity and larger spans, metal girders may be built up as single rolled sections or by riveting or welding plates with angles. A lot of people employ concrete girders as well. The most typical kind of bridge is the beam bridge. A beam bends to support vertical weights. The top of the beam bridge experiences horizontal compression as it bends. The bottom of a beam is also put under horizontal stress at the same time. By compressing vertically, the supports transfer the loads from of the beam to the foundations. Wood, steel, other metal, reinforced or restressed concrete, polymers, and even brickwork containing steel rods in the link between bricks may all be used to make beams [4], [5]. Metal beams are designed with a narrow vertical webbing and thicker horizontal flanges, which are where the majority of the strain is visible, in order to save weight. A bridge is referred to be a simply supported beams bridge if its only two supports are supported by beams. The bridge became continuous if two or even more beams are fixed securely together over supports.

Truss Bridge

In engineering, a truss is a structural element that is often made from straight pieces of metal or wood to create a number of triangles that are arranged in a single plane. (Stress cannot cause a triangle to deform.) A truss provides a stable shape that can sustain a large external load across a substantial length of space, with both the component sections under primary axial tension or compression stress. The panel points or truss joints are where the component sections cross. The top and bottom chords, which are the linked sections that make up the top and bottom of a truss, are referred to as such. The web of the truss is the collective name for the sloping and vertical parts joining the chords. Throughout the early Bronze Age, around about 2500 BC, simple lake homes were possibly where trusses were first utilised. The first trusses were made of wood. The Greeks made considerable use of trusses for roofing, and throughout the European Middle Ages, trusses were used for a variety of building projects. Plans for wood trusses were included in Quattro libri dell'architettura by Andrea Palladio. The construction of covered bridges in the United States during the early 19th century provided a significant stimulus for truss design. Steel replaced cast iron and wrought iron for railroad truss bridges. The Pratt and Warren systems are the two that are most often employed; throughout the former, the sloping web components are parallel to one another, while with the latter, those who alternate in slope direction. Additionally, trusses are employed in a variety of machines, including lifts and cranes, as well as in the wings and fuselages of aero planes. Because a single-span truss bridge bends to sustain vertical loads, it is analogous to a simply supported beam. The top chords (or horizontal components), bottom chords, and either compression or compression throughout the vertical and diagonally members, dependent on their orientation, are all affected by bending. Because they employ a relatively little quantity of material to support comparatively enormous loads in Figure 1, trusses are often used.

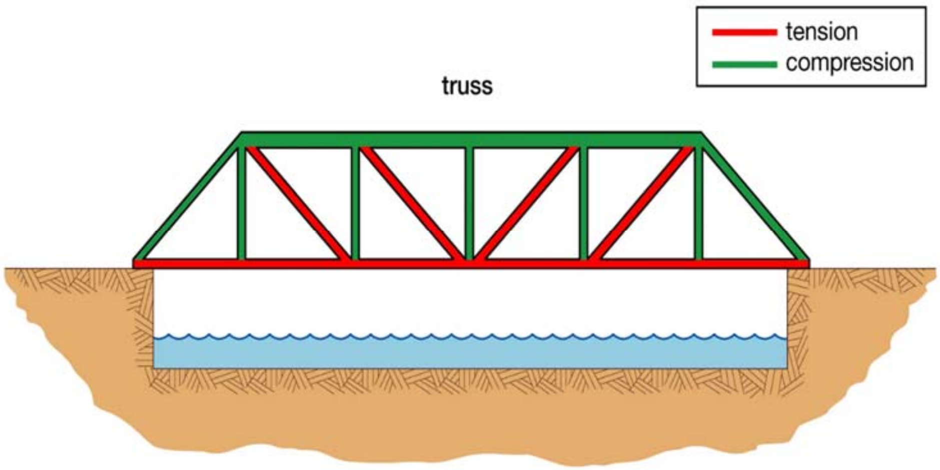

Figure 1: Illustrates the diagram of single-span truss bridge [6]**.**

Arch Bridge

In civil engineering and architecture, an arch is a curving element that spans an opening and supports loads coming from above. The vault developed from the arch as its foundation. The wedge is primarily what makes an arch. When a collection of wedge-shaped blocks—those with larger upper edges than lower edges—are arranged flank to flank as in the image, the outcome is an arch. Noussoirs are the name for these blocks. Each voussoir has to be accurately carved in order for it to carry weights evenly while pressing firmly on the surface of nearby blocks. The keystone refers to the centre voussoir. The spring, also known as the springing line, is the point where the arch rises from its vertical supports. The voussoirs need support from below during the building of an arch until the keystone is in place; this support often takes the shape of prefabricated timber centering. Semicircular, segmental, pointed, or two crossing arcs of a circle are all acceptable shapes for an arch's curve; noncircular curves may also be employed effectively. Arches provide a number of significant benefits over horizontal beams, or lintels, in masonry building. As contrast to a large, monolithic stone lintel, they may be constructed from compact, lightweight brick or stone pieces, allowing them to cross considerably larger openings. Additionally, an arch has a far higher load capacity than a horizontal beam. This carrying capacity results from the fact that pressure applied downward to an arch causes the voussoirs to be forced together rather than apart. In addition, these stresses have a tendency to press the blocks outward radially; pressures redirect these outward forces downward to generate a thrust force that, if improperly buttressed, can cause the arch to collapse. As a result, the pillars or vertical supports that an arch rests upon must be substantial enough to buffer the force and direct it into the foundations (as in Roman triumphal arches). However, when they are arranged in a row, arches may rest on thin supports since each arch's thrust balances the push of its neighbors, and the system is stable so long as the arches either at the of the row's ends are buttressed. Ancient Roman aqueducts and stone bridges with arches both use this technology.

Bibliography

[1] M. Kripka, V. Yepes, and C. J. Milani, “Selection of sustainable short-span bridge design in Brazil,” *Sustain.*, 2019, doi: 10.3390/su11051307.

[2] Y. Sha, J. Amdahl, and K. Liu, “Design of steel bridge girders against ship forecastle collisions,” *Eng. Struct.*, 2019, doi: 10.1016/j.engstruct.2019.109277.

[3] R. Mikhail *et al.*, “Development of nationwide surface spectral acceleration maps for earthquake resistant design of bridges based on national hazard maps of indonesia 2017,” *J. Eng. Technol. Sci.*, 2019, doi: 10.5614/j.eng.technol.sci.2019.51.4.4.

[4] Y. Purnomo Safaa, J. Utomo Dwi Hatmoko, and B. Purwanggono, “Evaluation of the use of prefabricated bridge elements with Design for Manufacture and Assembly (DfMA) criteria,” *MATEC Web Conf.*, 2019, doi: 10.1051/matecconf/201927005006.

[5] E. Ellobody, “Finite element modelling and design of composite bridges with profiled steel sheeting,” *Adv. Struct. Eng.*, 2017, doi: 10.1177/1369433216678865.

[6] P. N. Billington, “Bridge,” 2020. https://www.britannica.com/technology/bridge-engineering (accessed Dec. 26, 2022).

CHAPTER - 10

SUSPENSION BRIDGE

Mr. Ajay H A, Assistant Professor,
Department of Civil Engineering, Presidency University, Bangalore, Karnataka, India.
Email Id: - ajay@presidencyuniversity.in

Suspension bridges support its roadway with overhanging cables. Modern suspension bridges can cross greater lengths than any other kind of bridge because they are lightweight, visually beautiful, and strong. These are also among of the costliest to build. Although suspension bridges may be built to be sturdy enough to accommodate freight trains, they were almost all created with vehicular traffic in mind [1],[2]. Vertical loads are carried by tensioned, curved cables in suspension bridges. These loads are passed to the anchorages that must withstand the inward and occasionally vertical pull of the cables, as well as the towers, which convey them through vertical compression towards the ground [3], [4]. The towers are the only parts of the suspension bridge that are in compression, making it seem like an upside-down arch under tension. The deck must be carefully controlled to prevent excessive movement since it is suspended in the air. Therefore, the deck has to be either heavy, stiff, or both [5].

Form and Mechanics

In suspension bridges, curved, tensioned cables carry vertical stresses. These weights are transferred to the towers, which compress them vertically and transmit them to the ground, as well as the anchorages, which must bear the inward and sometimes vertical pull of cables. The suspension bridge seems to be an upside-down arch under tension since the towers are the only components that are under compression. Since the deck is suspended in the air, it needs to be properly managed to avoid excessive movement. The deck must thus be either hefty, rigid, or both. Since the early 20th century, deflection theory has been used in suspension bridge design to predict how the curved cables and horizontal deck would interact to carry weights.

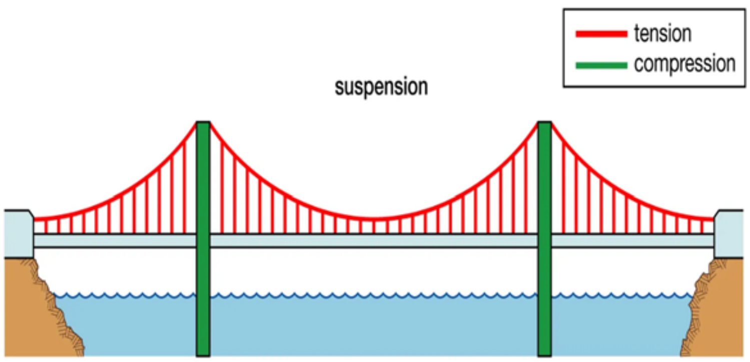

Figure 1: Illustrates the schematic diagram of Suspension Bridge [6]**.**

Josef Melan, an Austrian professor, initially proposed the deflection hypothesis in 1888. It explains how smoothly the deck and cables move together when subjected to gravity stresses. This hypothesis states that as spans lengthen and the weight of the suspended structure increases, the rigidity of the deck actually becomes less necessary. In order to achieve a lighter, more attractive appearance without compromising safety, engineers attempted to reduce the ratio of girder depths to span length during the 1930s, and deflection theory played a crucial part in design (Figure 1).

Construction of Suspension Bridge

For bridges across bodies of water that need piers, concrete caissons are dug into the riverbed and filled with concrete to serve as the foundation. Caissons are large wooden, metal, or concrete cylinders or containers. The caissons for suspension bridges are protected by towers. Suspension-bridge towers are now composed of steel or concrete instead of their original material of stone. Then, on both ends, the anchorages are built, often from reinforced concrete with steel eye bars built in to which the cables will be fastened. An eye bar is a metal rod with holes (or "eyes") at both ends. While early suspension bridges employed cables made of linked wrought-iron eye bars, modern cables are sometimes made of thousands of steel wires spun together on the construction site. Each wire is moved from one mooring to the next and back over the tops of the towers using rope pulleys that are used for spinning. Then, the wires are bundled and coated to prevent corrosion. After the cables are finished, suspenders are strung, and the deck is then built—typically by floating deck pieces out aboard ships, lifting them with cranes, then fastening them to the suspenders.

Cantilever Bridge

A beam is considered to be cantilevered when it projects outward and is only supported at one end. Three spans make up a cantilever bridge, one of which cantilevers out over the river to be crossed while the other two are moored to the shore. The centre span, which supports vertical loads via compression in the upper chords and tension pressures across the lower chords much like a truss or even a merely supported beam, is supported by the cantilevered arms that extend from the outer spans. The cantilevers sustain their loads by imparting tension to the upper chords and compression to the lower ones.

Compression via the inner towers transmits the pressure to the foundation, and tension through the outer towers to the far-off foundations. A cantilever is a beam that spans an area that is not supported, is supported at one end, and supports weight at the other. The top half of the thickness of such a beam receives tensile stress, which has the tendency to stretch the fibres, and the bottom half experiences compressive stress, which has the tendency to crush them. Cantilevers are often employed in both the design and construction of machines and structures.

A cantilever is created in construction when a beam is put into a wall with its ultimate limit extending. Longer cantilevers are used to support a gallery, roof, canopy, runways for an overhead travelling crane, or even a piece of the building when a project requires extra space below. In certain areas, cantilever construction is utilised to create bridges with large spans, especially for heavy loads; the Forth Bridge in Scotland, which has three cantilevers and two connecting suspended arches, is a famous example. Every time a sizable area has to be served, such as at shipbuilding docks and steel stockyards, cantilever cranes are needed. The large hammerhead excavators, which have a 300-ton capacity, are employed to operate on ships that are being fitted up at ports after leaving the yards. These machines have a fixed tower and a pivot that will lean down to spin the same cantilever within a circle. The cantilever girders on each side of the central travelling tower are supported by the lighter kinds [6].

Bibliography

[1] R. N. Møller, S. Krenk, and M. N. Svendsen, "Damping system for long-span suspension bridges," *Struct. Control Heal. Monit.*, 2019, doi: 10.1002/stc.2448.

[2] J. Martin, A. Alipour, and P. Sarkar, "Fragility surfaces for multi-hazard analysis of suspension bridges under earthquakes and microbursts," *Eng. Struct.*, 2019, doi: 10.1016/j.engstruct.2019.05.011.

[3] N. S. Dang, G. T. Rho, and C. S. Shim, "A master digital model for suspension bridges," *Appl. Sci.*, 2020, doi: 10.3390/app10217666.

[4] W. Petersen, O. Øiseth, and E. Lourens, "Investigation of dynamic wind loads on a long-span suspension bridge identified from measured acceleration data," *J. Wind Eng. Ind. Aerodyn.*, 2020, doi: 10.1016/j.jweia.2019.104045.

[5] K. H. Ostenfeld, "Evolution of suspension bridges," *Hormig. Y Acero*, 2019.

[6] P. N. Billington, "Bridge," 2020. https://www.britannica.com/technology/bridge-engineering (accessed Dec. 26, 2022).

CHAPTER - 11

CABLE-STAYED BRIDGE

Dr. Shrishail B Anadinni, Professor and Associate Dean (Core Branches),
Department of Civil Engineering, Presidency University, Bangalore, Karnataka, India.
Email Id: - shrishail@presidencyuniversity.in

The term "cable-stayed bridge" refers to a kind of bridge where the weight of the deck was supported by many tensioned, almost straight, diagonal cables that run parallel to one or even more vertical towers. Through vertical compression, the towers transmit the cable stresses to the foundations [1], [2]. The deck was also compressed horizontally by the tensile pressures in the cables. The cantilever technique is often used to build cable-stayed bridges, therefore the process starts with the caissons being sunk and the building of towers with anchorages. One cable and a portion of the deck are installed in each direction once the tower is completed. Before moving on, the deck is rest retched in each segment [3],[4]. Up until the deck portions meet in the center and are linked, the procedure is repeated [5]. The abutments serve as anchors for the ends. The designer of a cable-stayed bridge has a wide range of options for both the deck and cabling materials as well as the geometric configuration of the cables. By virtually straight diagonal cables under tension, cable-stayed bridges support the vertical main-span stresses. Through vertical compression, the towers transmit the cable stresses to the foundations. In Figure 1, the tensile pressures inside the cables also compressed the deck horizontally.

Early versions, like the Strömsund Bridge from Sweden (1956), supported the deck at two distant sites using simply two cables that were tied at virtually the same position high on the tower. In comparison, the Oberkasseler Bridge, which was constructed in Düsseldorf, Germany, over the Rhine River in 1973, used a single tower throughout the middle of its own twin 254-metre (846-foot) spans. The four cables were arranged in a harp or parallel configuration, equally spaced along the center line of the deck and up the tower. The Bonn-Nord Bridge near Bonn, Germany (1966) became the first significant cable-stayed bridge to utilise a lot of thinner cables rather than a lot of heavier ones. This had the technical benefit that more cables allowed for the use of a thinner deck. Such multiscale configurations eventually spread widely. The Bonn-box Nord's girder deck was composed of steel, like the case with the majority of cable-stayed bridges constructed in the 1950s and 1960s. However, concrete decks started to be utilised more often in the 1970s (Figure 1).

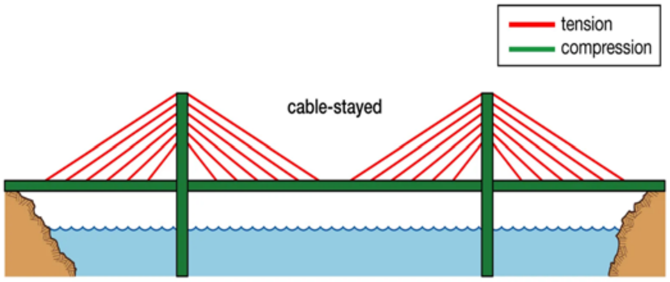

Figure 1: Illustrates the schematic diagram of cable stayed bridge [6]**.**

Materials

Wood, stone, iron, and concrete have traditionally been the four main building materials used for bridges. Iron has had the most impact on contemporary bridges of all of them. Steel is created from iron, and prestressed and reinforced concrete are both constructed using steel. Almost entirely, steel, concrete reinforcement, and prestressed concrete are used in the construction of modern bridges.

Wood and Stone

Despite being rather weak in tension and compression, wood has virtually always been readily accessible and reasonably priced. For tiny, light-duty bridges like footbridges, wood has been utilised successfully. Some contemporary bridges now include laminated hardwood beams and arches. While weak under stress, stone is powerful under compression. Its main uses have been in abutments, piers, and arches.

Iron and Steel

Cast iron, which is strong when compressed but weak in tension, was the first kind of iron utilised during the Industrial Revolution. Contrarily, wrought iron has a substantially higher tensile strength and is just as strong in compression as ductile iron. Iron has been refined even further to become steel, which is stronger than any iron and outperforms it both in tension and compression. Steel may be produced in a variety of alloys, some of which are five times more durable than others. These are high-strength steels, according to the engineer.

Concrete

Concrete is a synthetic stone created by combining water, sand, gravel, and a binder like cement. It is powerful in compression but also weak in tension, much like stone. Reinforced concrete is concrete that has steel bars inserted throughout it. Because the steel bears all of the stress, reinforcement enables less concrete to really be utilised. Additionally, the concrete shields the steel from rust and fire. One significant variety of reinforced concrete is prestressed concrete. In a common procedure known as post-tensioned prestressing, reinforced concrete beams were cast with longitudinal holes accommodating steel tendons (cables or bars), however the holes are curved upwards towards end to end, as well as the tendons, once placed inside, were stretched and then attached at the ends. The two attached ends are pulled together by the tendons, which are now under intense stress, compressing the beam. Additionally, the curved tendons produce an upward pull, which the designer may use to counterbalance most of the downward load that the beam is anticipated to carry. Prestressed concrete results in lighter layouts that are frequently less costly than designs using reinforced concrete since it minimizes the quantity of steel and concrete required in a construction.

Live Load and Dead Load

A bridge's main use is to transport trains, large trucks, and other types of vehicles. The traffic loading must be estimated by engineers. It is feasible that the largest weight imaginable will be carried across small spans; specifically, four large trucks may pass simultaneously, two in each direction, over spans less than 30 metres (100 feet). The expense of planning for the highest feasible load is exorbitant for longer spans of 1,000 metres or more since it is such a distant possibility (just picture the Golden Gate Bridge with large vehicles driving bumper to bumper in both directions). Therefore, probable loads are used by engineers as a foundation for design. The structure must be able to support some weight in order to transport traffic, and on short spans, this gravity loads weight is often lower than the active loads. However, for larger spans, the dead load was higher than the live load, making it more crucial to design shapes that reduce dead load. Beams, hollow boxes, trusses, arches, other continuous variations of the same are often used to construct shorter spans, whereas cantilever, cable-stay, and suspended forms are used to construct larger spans. Questions of shape, substance, and form become more significant as spans lengthen. To give longer spans with greater strength from less material, new shapes have emerged.

Bibliography

[1] L. Zhang, G. Qiu, and Z. Chen, "Structural health monitoring methods of cables in cable-stayed bridge: A review," *Meas. J. Int. Meas. Confed.*, 2021, doi: 10.1016/j.measurement.2020.108343.

[2] J. Wen, Q. Han, Y. Xie, X. Du, and J. Zhang, "Performance-based seismic design and optimization of damper devices for cable-stayed bridge," *Eng. Struct.*, 2021, doi: 10.1016/j.engstruct.2021.112043.

[3] M. M. Alamdari, N. L. Dang Khoa, Y. Wang, B. Samali, and X. Zhu, "A multi-way data analysis approach for structural health monitoring of a cable-stayed bridge," *Struct. Heal. Monit.*, 2019, doi: 10.1177/1475921718790727.

[4] L. Ren, Z. Fang, and K. Wang, "Design and behavior of super-long span cable-stayed bridge with CFRP cables and UHPC members," *Compos. Part B Eng.*, 2019, doi: 10.1016/j.compositesb.2018.11.060.

[5] Y. Zhou and L. Sun, "A comprehensive study of the thermal response of a long-span cable-stayed bridge: From monitoring phenomena to underlying mechanisms," *Mech. Syst. Signal Process.*, 2019, doi: 10.1016/j.ymssp.2019.01.026.

[6] P. N. Billington, "Bridge," 2020. https://www.britannica.com/technology/bridge-engineering (accessed Dec. 26, 2022).

CHAPTER - 12

BRIDGE DESIGN

Mr. Dayalan J, Assistant Professor,
Department of Civil Engineering, Presidency University, Bangalore, Karnataka, India.
Email Id: - dayalanj@presidencyuniversity.in

Forces of Nature

While natural forces can be either vertical or horizontal, dead and living weight are basically vertical weights [1],[2]. Two significant loads are produced by wind, one of which is static while the second is dynamic [3]. The horizontal force that seeks to tip a bridge is known as static wind load. Dynamic wind load causes oscillations in either direction by causing vertical motion. Oscillations are vibrations that might also lead to a bridge failing, much as how a violin string breaks after being overworked. A thin, improperly designed, and unsupported deck might suffer severe torsional (twisting) or vertical motions. By using expansion joints throughout the deck and bearings there at abutments and pier tops, the expansion and compression of bridge materials caused by heat and cold have indeed been reduced to a minimum. With the aid of bearings, the bridge can respond to changing temperatures without damaging the material. Engineers sometimes utilise hinges in arches to lessen strains brought on by temperature changes. Modern bridges must be able to endure natural calamities like earthquakes and tropical storms. Structures with as little dead weight as possible are often the best at withstanding earthquakes because of horizontal forces that result from ground acceleration and braking are inversely proportional towards the weight of the structure [4], [5]. The basic Newtonian rule that states that force equals linearly proportional acceleration provides an explanation for this phenomena. The bridge should be aerodynamically built to have minimal solid material confronting the winds during cyclones so that the winds may travel through or around it without creating hazardous oscillations [6].

Types of Design and Detailing Errors in Construction and their Prevention

Common design and detailing mistakes occur in construction as a result of either poor structural design or a disregard for relatively small design features. The many design and detailing mistakes in building, their symptoms, and preventative strategies are listed below:

Inadequate Structural Design

Concrete that has been subjected to more stress than it can tolerate or whose strain has increased above its strain capacity due to poor structural design collapses. Concrete will either crumble or fracture as a result of such failures caused by poor structural design. Concrete may spall owing to too high compressive stress brought on by poor structural design. High torsion or shear forces may also cause concrete to spall or fracture. Concrete may fracture as a consequence of high tensile pressures. The structure must be investigated, and the locations of the damage must be compared to the sorts of stresses that ought to be present in the concrete, in order to pinpoint the poor design as the root cause of the structural damage. Thorough petrographic investigation and concrete strength testing from reused materials will be required for restoration operations. Prevention:

Carefully and thoroughly reviewing all design calculations may help to avoid structurally inadequate designs. Any restoration technique that utilizes pre-existing concrete structural components has to be thoroughly examined.

Poor Design Details

Even if the design is sufficient to satisfy the requirements, poor design details might result in a concentrated localized area of high stresses in structural elements. Concrete may fracture as a result of these high strains, allowing chemicals or water to get through. Therefore, a lack of design detail might cause structural parts to leak. Although poor design details may not result in structural collapse, they may be the reason why concrete deteriorates. A comprehensive and meticulous assessment of the building work's plans and specifications may help to avoid these issues. We cover many forms of poor design details and their repercussions on buildings:

Abrupt Changes in Section

Unexpected variations in section might lead to stress concentrations and cracking. The use of relatively thin pieces tightly connected into large sections or patches and replacements concrete with irregular plan dimensions are common examples.

Insufficient Reinforcement at Corners and Openings

Openings and corners often lead to stress concentrations that may result in cracking. The best course of action in this situation is to offer more support where stress concentrations were anticipated.

Inadequate Provision for Deflection

The loading of components or sections may exceed the capacity for which they were constructed if deflections are greater than those predicted. Usually, these loadings will cause cracking in the walls or partitions.

Inadequate Provision for Drainage

Water may pond in a building if the drainage process is not done properly. This ponding might cause concrete to leak or get saturated. The inside of the building might be harmed by leakage, and the structure itself could get stained and encrusted. If the building is located in a location where there is frequent freezing and thawing, saturation might lead to seriously damaged concrete.

Insufficient Travel in Expansion Joints

Concrete beside expansion joints may spall if they are not constructed properly as expansion joints. The specification for transverse reinforcement should take into consideration the whole range of potential temperature differentials that what a concrete may be anticipated to encounter. There isn't a single expansion joint that can accommodate all temperature difference situations.

Incompatibility of Materials

When materials with various properties—such as those with different elastic moduli or coefficients of thermal expansion—are used next to one another and the construction is stressed or exposed to seasonal or daily temperature changes, it may fracture or splinter.

Neglect of Creep Effect

Similar consequences to those of poor deflection supply may result from neglect of creep. Furthermore, failing to account for creep in members made of prestressed concrete might result in excessive prestressed loss, which would then cause cracking when loads are applied.

Rigid joints between Precast Units

Precast element designs must allow for mobility between precast components that are next to each other and between the precast elements as well as the supporting frame. Inability to account for this movement may lead to spalling or cracking.

Unanticipated shear stresses in piers, columns, or Abutments

If expansion bearing assemblies were allowed to freeze due to poor maintenance, horizontal loading might be transmitted to the concrete components supporting the bearings. Concrete will fracture as a consequence, which is often accompanied by additional issues that the water intrusion will bring about.

Bibliography

[1] M. Kripka, V. Yepes, and C. J. Milani, "Selection of sustainable short-span bridge design in Brazil," *Sustain.*, 2019, doi: 10.3390/su11051307.

[2] Y. Sha, J. Amdahl, and K. Liu, "Design of steel bridge girders against ship forecastle collisions," *Eng. Struct.*, 2019, doi: 10.1016/j.engstruct.2019.109277.

[3] R. Mikhail *et al.*, "Development of nationwide surface spectral acceleration maps for earthquake resistant design of bridges based on national hazard maps of indonesia 2017," *J. Eng. Technol. Sci.*, 2019, doi: 10.5614/j.eng.technol.sci.2019.51.4.4.

[4] J. H. Lee, J. J. Park, and H. Yoon, "Automatic bridge design parameter extraction for scan-to-BIM," *Appl. Sci.*, 2020, doi: 10.3390/app10207346.

[5] H. Beade-Pereda, "Bridge Design, Perception, and Emotion," *Struct. Eng. Int.*, 2021, doi: 10.1080/10168664.2021.1936351.

[6] P. N. Billington, "Bridge," 2020. https://www.britannica.com/technology/bridge-engineering (accessed Dec. 26, 2022).