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**TITLE OF COURSE:** [**FUNDAMENTALS OF BRIDGE DESIGN AND MODELING**](https://www.udemy.com/course/fundamentals-of-bridge-designyour-way-to-be-bridge-designer/)

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**Introduction to the course**

 This course covers fundamental concepts and methods in bridge. Starting with the very basics, we consider **definition of the bridge, the history of bridge and bridge design. It will highlight on the different types bridges, how a bridge works, load transfer in bridges, main bridge components, bridge type selection, bridge planning and geometric design. Besides, it will also expand on bridge design methods, design loads of bridges, different loads affecting and structural design and design drawings.**

A bridge is a construction made for conveying the road traffic or other moving loads in order to pass through an obstacle or other constructions. The required passage may be for a railway, pedestrians, a pipeline a canal, a road etc. The Obstacle can be valleys, rivers, sea channels, and other constructions, such as buildings, bridges, road, or railways. The prototypical bridge is quite simple. Two supports holding up a beam. But the engineering issues that has to be overcome even in this simple form are [inherent](https://www.merriam-webster.com/dictionary/inherent) in every bridge: the supports need to be strong enough to hold the structure up, and the [span](https://www.britannica.com/technology/span) between supports must be very strong also to carry the loads. Spans are normally made as short as possible; long spans are justified where good foundations are few, for instance over estuaries where the water is deep. Therefore, bridge design that best serves the public interest to be economical, efficient, and elegant as is safely possible [1]. Economy is a social principle that puts value on cutting the costs of [construction](https://www.britannica.com/technology/construction) and maintenance while retaining efficiency. [Efficiency](https://www.merriam-webster.com/dictionary/Efficiency) is a scientific principle that puts a value on reducing materials while increasing performance. Finally, elegance is a principle that puts value on the personal expression of the designer without compromising performance or economy.

Since the early 19th century, modern designers have written about [aesthetics](https://www.merriam-webster.com/dictionary/aesthetics) or elegance starting with [Thomas Telford](https://www.britannica.com/biography/Thomas-Telford), the Scottish engineer. Bridges ultimately belong to the general public, which is the final arbiter of this issue, but in general there are three positions taken by professionals. The first principle holds that the structure of a bridge is the province of the engineer and that beauty is fully attained only by the addition of [architecture](https://www.britannica.com/topic/architecture) [2]. The second idea is that from the standpoint of pure engineering, bridges making the most efficient possible use of good and superior materials are by design beautiful. The third idea holds that architecture is not needed but that engineers must be innovative and think very well on how to make the structure beautiful. This last principle acknowledges the fact that engineers have many possible choices of roughly equal efficiency and economy and can therefore express their own [aesthetic](https://www.merriam-webster.com/dictionary/aesthetic) ideas without adding importantly to cost or materials. Bridges are designed, first, to carry their own dead load or permanent weight, to carry live loads or traffic, and to resist natural forces such as earthquakes or winds. On a general note, bridges can be divided into two categories: or unique-design bridges over rivers, or estuaries or chasms or standard overpass bridges. This article dwells on the features common to both types, but it highlights on the unique bridges because of their greater economic, technical, and aesthetic interest [3] [14].

##  The history of [bridge design](https://www.britannica.com/technology/civil-engineering). Modern bridges, have evolved more than 200 years ago as engineers came to better understand the possibilities [inherent](https://www.merriam-webster.com/dictionary/inherent) in [cast iron](https://www.britannica.com/technology/cast-iron), then in [wrought iron](https://www.britannica.com/technology/wrought-iron) and structural [steel](https://www.britannica.com/technology/steel), and finally in reinforced and prestressed [concrete](https://www.britannica.com/technology/concrete-building-material). These materials used to design bridges that broke completely when the designs using wood or stone that characterized bridges before the [Industrial Revolution](https://www.britannica.com/event/Industrial-Revolution). Industrial strength has been a significant factor in the evolution of bridges. [Great Britain](https://www.britannica.com/place/Great-Britain-island-Europe), the leading industrialized country of the early 19th century, built the most important bridges of that time. In the same vein, from the late 19th century through the mid-20th century, [innovations](https://www.merriam-webster.com/dictionary/innovations) springs up in the [United States](https://www.britannica.com/place/United-States) and in [Japan](https://www.britannica.com/place/Japan) and [Germany](https://www.britannica.com/place/Germany) in subsequent decades. [Switzerland](https://www.britannica.com/place/Switzerland), became a highly industrialized society, also became a growing ground for building of bridge. In the early 21st century, so many world’s longest viaducts for its [high-speed railways](https://www.britannica.com/technology/High-Speed-Train-British-passenger-train) where built by China [14] [18].

**Types of bridges**

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**Beam Bridge:**

It is a horizontal bridge supported at each end by piers. The weight at the top of the beam pushes straight down into the piers It is the most common type of bridge. A [beam](https://www.britannica.com/technology/beam-architecture) carries vertical loads by bending. it undergoes horizontal compression on the top as the beam bridge bends, while the bottom of the beam is subjected to horizontal [tension](https://www.britannica.com/science/tension-physics). The supports convey the loads from the [beam](https://www.britannica.com/dictionary/beam) by [compression](https://www.britannica.com/science/compression) vertically to the [foundations](https://www.britannica.com/technology/foundation-construction). It is a supported beam bridge, when the bridge is made up of beams spanning between only two supports. But If two or more beams are joined tightly together over supports, the bridge becomes continuous [4].

Bridges need to be tight and safe at the abutments and foundations. In the case of a normal overpass beam bridge with one support in the middle, [construction](https://www.britannica.com/technology/construction) starts with the casting of concrete footings for the abutments and [pier](https://www.britannica.com/technology/pier-architecture). When the texture of the soil is mainly weak, steel or wooden [piles](https://www.britannica.com/technology/pile-construction) are driven to support the footings. After the concrete abutments and piers and have hardened very well, the erection of a concrete or steel superstructure starts. Steel [beams](https://www.britannica.com/technology/beam-architecture) are normally produced in a factory, shipped to the site, and placed in positions by cranes. Steel [beams](https://www.britannica.com/dictionary/beams) whose spans are short are normally formed as a single unit. At the site, they are placed sideways to each other, with temporary forms between them so that a concrete deck can be cast on top. The beams normally have pieces of welded metals on their top flanges, around which the concrete is poured. These metal pieces provide a connection between beam and slab, thereby producing a composite structure. For spans that are longer, steel beams are made in the form of plate [girders](https://www.britannica.com/technology/girder). A plate girder is a beam comprising of a bottom flanges welded or bolted to a vertical web and a separate top. While beams that have short spans are normally of a constant depth, beams that has longer spans are mostly haunched—that is, at the supports it is deeper and shallower at mid-span. Haunching stiffens the [beam](https://www.britannica.com/dictionary/beam) at the supports, therefore reducing bending at mid-span.

Arch Bridge: Arch shaped and have abutments at each end. The weight of the bridge is transferred into the abutments at either side. [Arches](https://www.britannica.com/technology/arch-architecture) are normally constructed on-site. After the construction of abutments (and piers, if the bridge is multiarch), a [falsework](https://www.britannica.com/technology/falsework) is constructed. For a concrete arch, metal or wooden falsework and forms hold the cast concrete and are later removed. For steel arches, a cantilevering method is the best. Each side of an arch is built out toward the other, supported by temporary cables above or by falsework below until the ends meet. At this stage the arch becomes self-supporting, thereafter the falsework or cables are released. The [arch](https://www.britannica.com/technology/arch-architecture) bridge carries loads primarily by compression, which [exerts](https://www.britannica.com/dictionary/exerts) on the foundation both vertical and horizontal forces. Arch foundations must therefore prevent both vertical settling and horizontal sliding. In spite of the more complicated foundation design, the structure itself normally requires less material than a beam bridge of the same span. A basic curve span works by moving its weight and different loads somewhat into an even pushed limited by the solid projections at one or the other side. The curve rib necessities to convey twisting second, shear force, and pivotal power in genuine help conditions. A viaduct (a long extension) might be produced using a progression of curves albeit other more affordable constructions are ordinarily utilized today. For statically uncertain curve spans, the inside powers will happen because of the temperature variety and settlement of supports. Therefore, on the off chance that the curve spans are developed in delicate soil establishments, the scaffold deck is by and large intended to support the even powers [3].

Truss Bridge: Trusses are used to stiffen and support a bridge by distributing the load and forces acting upon the bridge based on the positions of the vertical, horizontal and diagonal chords. Bracket spans are probably the most established kind of current scaffolds. For the estimation to be improved on the supports are regularly accepted as stuck association between adjoining bracket individuals. Hence, the support individuals like verticals, harmonies, and diagonals act just in one or the other pressure or strain. For present day bracket spans, gusset plate associations ordinarily utilized, then, at that point, bowing minutes and shear powers of individuals ought to be considered for assessing the genuine exhibition of the support spans, which is accomplished by the guide of limited component programming. For the plan perspective, in any case, the stuck association supposition that is considered for security concerns and furthermore for working on the underlying model and investigations. A solitary range bracket span resembles a basically upheld shaft since it conveys vertical burdens by twisting. Twisting prompts pressure in the top harmonies (or flat individuals), strain in the base harmonies, and either pressure or pressure in the vertical and askew individuals, contingent upon their direction. Brackets are famous because of the way that they utilize a generally modest quantity of material to convey moderately huge burdens. Also, as the hub powers (yet not twisting minutes and shear powers) are for the most part administers the pressure states of the individuals, such supposition for the most part won't cause huge blunders between the genuine spans and the plan models [3].

Suspension Bridge**:** It has cables suspended between towers, plus vertical suspenders which carry the weight of the deck which is the load bearing portion.When bridges needing [piers](https://www.britannica.com/technology/pier-architecture) are constructed over a body of water, foundations are made by sinking [caissons](https://www.britannica.com/technology/caisson) into the riverbed and filling them with concrete. Caissons are large boxes or cylinders that have been made from concrete, metal or wood. In the case of [suspension](https://www.britannica.com/dictionary/suspension) bridges, towers are built on the top of the caissons. The first suspension-bridge towers were stone, but now they are either concrete or steel. Next, the anchorages are constructed on both ends, normally of reinforced concrete with embedded steel [eye bars](https://www.britannica.com/technology/eyebar) by which the [cables](https://www.britannica.com/technology/cable-wire-rope) will be tied to it. An eye bar is a length of metal with a hole or an eye at the ends. Cables made of thousands of steel [wires](https://www.britannica.com/technology/wire) are fastened or spun together at the construction site. The Spinning is normally carried out by rope pulleys that convey each wire across the top of the towers to the opposite anchorage and back. To prevent corrosion, the wires are then bundled and covered. When the cables are complete, suspenders are hung, and finally the deck is erected. This is done by floating deck sections on ships, while cranes do the hoisting, and securing them to the suspenders [12][16].

A Cantilever bridges like suspension bridges, normally carry heavy loads over water, so their [construction](https://www.britannica.com/technology/construction) starts with the sinking of caissons and the erection of towers and anchorages. For steel cantilever bridges, the steel frame is built out from the towers toward the center and the abutments. When a shorter central span is required, it is normally floated out and raised into place. The last element that is added is the deck. The cantilever method for erecting [prestressed concrete](https://www.britannica.com/technology/prestressed-concrete) bridges involves building a concrete cantilever in short segments, prestressing each succeeding parts onto the earlier ones. Each new member is supported by the previous segment while it is being cast, thereby [avoiding](https://www.britannica.com/dictionary/avoiding) the need for falsework. Cabled stayed bridge: Like suspension bridges, cable-stayed bridges are held up by cables. However, in a cable-stayed bridge, less cables are required and the towers holding the cables are proportionately. Construction of cable-stayed bridges usually done using the cantilever method. After the tower is built, one cable and a section of the deck are constructed in different direction. Before continuing each section of the deck is prestressed. The process is repeated until the parts or sections of the deck meet in the middle, where they are connected. The ends are held firmly at the abutments [11].

 How a bridge works. Loads are applied to the deck. The deck transmits the live loads and dead loads to the superstructure [beams]. The superstructure transmits these loads and the superstructure dead loads to the substructure. The substructure transmits all these loads and the substructure dead loads to the earth. The earth supports the bridge and all its loads. It is all about load paths. Load transfer in beam bridges: The beam type is the simplest type of bridge. The beam bridge could be anything as simple as a plank of wood to a complex structure. It is made of two or more supports which hold up a beam. Load transfer in arch and truss bridges:In design theory, the individual members of a simple truss are only subject to tension and compression and not bending forces. In most parts, all the beams in a truss bridge ate straight. Load transfer for suspension and cable stayed bridges**:** Cabled stayed bridges works by tension and compression. Load transfer for cantilever bridges;Cantilever bridge are built using cantilever horizontal beams supported on only one end. Most cantilever bridges use a pair of continuous spans that extends from opposite sides of the supporting piers to meet at the center of the obstacle the bridge crosses [9][11].

 The Main Bridge Components. The Bridge structures are comprising of substructure, superstructure, bearings, and accessories. The substructure of a bridge is the component that supports the superstructure and distributes the load to the bridge footings and foundation.

Fig 3A.

Fig 3B

Substructure is the portion of the bridge below the bearing, it is meant for supporting the bridge superstructure and send all those loads to the foundation or ground. As shown in figure 3A and B. The bridge substructures include abutments, piers, wing walls, or retaining walls, and foundation structures like columns and piles, drilled shafts that made of masonry, wood, stone, steel and concrete. Both piers and abutments are vertical structures used for supporting the loads from the bridges bearings or directly from the superstructures and for transferring the load to the foundation. However, the abutment refers to the supports located at the end or beginning of the bridge. While the piers are the intermediate supports. Thus, a bridge with a single span has only abutments at both ends, while multispan bridges also need intermediate piers to support the bridge superstructure [5].

The Piers. There are two basic types of piers. Colum piers and wall piers. Concrete column piers have a solid cross-section or a box section which may be the shape chosen for the cross section for aesthetic or structural reasons. Wall piers are mostly less pleasing from aesthetic point of view but they are less economical. They are preferred in cases where some condition exists, like in rivers where there are high hydrodynamic forces or in bridges that has tall piers where box sections are used. There is also solid wall pier, hammer head pier, and rigid frame pier [6].

 Abutments; The abutments maintain the connection between the bridge superstructure and the embankments. They are put in place to support the loads due to the superstructure which are transferred through the bearings and to the pressures of the soil contained by the abutment. The abutments should include expansion joints, so that it will they will cater the displacement of the deck which is the longitudinal expansion and shortening motion of the deck because of change in temperature. There are two main types of abutments: The counterfort wall abutment which is used when the topography and shapes of the backfill is such that open abutment cannot be used. The counterfort wall abutments are normally used when the required height of the front wall is above 5 to 8 meters. Nevertheless, if the depth is below the order of magnitude, counterfort walls may not be needed, rather a simple wall cantilevering from the foundation may be adopted. The connection between the abutments and the backfill may include an approach slab that enhances a smooth surface of the pavement even after foundation of the adjacent backfill.

Bridge superstructure which is the longitudinal system of a bridge can be one of the following, arch, beam, cable stayed or suspension and frame. Superstructure is the part of a bridge supported by the bearings The box girder, the slab and the beam-slab are the main types of the bridge transverse system. Bridge superstructures, the beam, truss, deck girder, plate girder or box girder structural systems. However, the deck system uses a reinforced concrete slab or an orthotropic steel plate. The deck directly carries traffic, while other portions of the superstructure carries the loads passing over it and transfer them to the substructures. The superstructure may include several components, such as the stringers, floor beams, bracing, and trusses or may include a few components, such as reinforced concrete slab in a slab bridge [13].

A bridge bearing is an element of a bridge transferring the loads obtained from the deck on to the substructure and to allow controlled movement due to seismic activity or variation in temperature and thus reduce the stresses involved. A bearing is the boundary between the substructure and the superstructure.

Accessory: Bridge accessories are structure members subordinate to the main bridge structure, such as track slabs, service ducts, and parapets. Deadweight of accessory structures shall be considered in the design, but their load carrying capacities are usually neglected [6].

 Bridge types selection. The selection of the correct type of bridge is determined based on the results of traffic survey, topographic survey, geological survey, meteorological survey, geotechnical survey, hydro technical survey, and seismic survey, etc., as well as the environmental impact, cost, and esthetics. While, the maximum span length (or spanning capability) is normally an important factor that should be considered for designing the bridge superstructure because of the fact that each bridge type has its own scope of application. Determination of the bridge superstructures is closely related to the use of construction materials. Because of the materials used for superstructure construction, the modern bridges can be roughly divided into steel bridges and concrete bridges with different structural forms. Advantaged by the high strength to weight ratio, steel construction requires lesser material than other traditional technologies and contributes to reducing a bridge’s environmental impact. The steel bridges are generally built in large spans such as truss bridges, arch bridges, cable-stayed bridges, and suspensions bridges. Especially for large span bridges, as the dead weight cares for the load carry capacity of bridges, the bridge superstructures are built in steel but not concrete. Concrete is a brittle material, like stone, nice in compression but weak in tension, so it is vulnerable to crack under twist or bending. Concrete reinforcement with steel improves its ductility, naturally its emergence follows the emergence of steel. But, for some structural forms of bridges, concrete will be a perfect material to build, such as the arch bridges whose members are mainly under compression. Also, concrete bridges are also widely used for short-span bridges due to the reasonable low cost and less maintenance in service stage. Additionally, with the development of the prestressing technique, the prestressed concrete bridges can also be constructed in medium spans. The presence or availability of the construction materials should be a determining factor in the selection of the bridge superstructures.

However, the mechanical characteristics of each bridge type are the determinant factor for an appropriate span capacity. Based on the above discussion, the simply supported structure is statically determinate and is simplest to design, and normally is suitable for short-span bridges. When unyielding foundation is attainable, the arch and bridges rigid-frame bridges can provide the most economical solution for span length. For medium-span bridges, the arch bridges, the continuous girder bridges, and the truss bridges can be considered as an alternative. But for large span bridges longer than 500 m, the suspension bridges and the cable-stayed bridge are promising solutions. A cable-stayed bridge is the successor to the suspension bridge for spans up to 600 m, and the largest span of cable-stayed bridge 1104 m. Nevertheless, for super bridges with span length greater than 1000 m, a suspension bridge is still the best choice. The foundation of the bridge is another factor that can affect the selection of the bridge superstructures. When a foundation that is unyielding attainable for building the intermediate piers, then continuous girders supported by independent piers and multispan rigid frames will be an appropriate option. When a foundation that is unyielding is what is available for building the abutments, the rigid-frame and the arch bridge can be considered. For soft foundations, other bridge types with larger spanning capacity should be chosen to avoid the intermediate piers. In summary, each bridge type has its own suitable range of application and should be a determining factor in the selection of the bridge superstructures. Additionally, other factors such as the environment impact, cost, and esthetics also need to be factored to obtain suitable alternatives for bridge superstructure [3].

BRIDGE PLANNING AND GEOMETRIC DESIGN

 A bridge must be functional, economical, beautiful and safe. The design philosophy for modern bridges are the same among different design codes of different countries. For example, the bridge design philosophy specified in Japanese bridge design specification is shown in figure 4.



Figure 4. Bridge survey and design process.

 In designing a bridge, the durability, reliability, environmental compatibility, fitness to the purpose of use, securing of the construction quality, safety of structures, ease of maintenance, and economy should be taken into cognizance.

The fitness to the purpose of use implies that the bridge’s function of being available to traffic as planned, including the serviceability for users to use it comfortably and safely. The bridge safety conveys the idea that the bridge has enough load carrying capacity to live loads, dead loads, seismic load, etc., that may occur in the service stage of the bridge. The durability means that with aging, the performance of a bridge will not undergo main degradation with respect to the bridge serviceability and safety. Securing of the constructability implies that the proposed bridge design should be able to be attained by using the technology available and ensuring the structural safety in both the construction stage, the service stage, and the durability.

Reliability and ease of maintenance implies that the repair and replacement of elements shall be performed easily when deterioration or damage occurs. Reasonable maintenance planning method in the design stage as design preconditions is very important. Environmental compatibility entails that the impact of the bridge construction on features of local environment, such as wildlife along river banks, marine life, flora and fauna along river banks, riverbed, archeological sites, etc., need to be factored. Then the economic efficiency, implies that the life cycle cost of the bridge should be reduced. The life cycle cost means the sums up of all relevant costs of a bridge structure over a given study period not only include the initial cost but also include the inspection cost, future rehabilitation costs, maintenance and, and the removal cost. The serviceability (without large deformation or severe cracking, etc.) during the life span of the bridge should be able to be guaranteed. The bridge elegance must come from the shapes, proportions, that which have to evidence and express

this flow of force, slenderness and transparency will come from a reduced and so efficient use of building materials. Functionality and Esthetics are inseparable; the designers must achieve architectural perfection in a full respect of structural, functional, and financial need. The bridge engineers should always work together with architecture or artist to explicitly express the structural concept in order for them to achieve their goals.

The bridge survey mainly includes the traffic survey, topographic survey, geological survey, hydro technical survey, seismic survey, and meteorological survey. The first thing to be undertaken is the traffic survey in order to predict the amount of traffic at various stages during the service life of the bridge in a bid to demonstrate the need and significance of the new bridge. The topographic and geological survey are thereafter done to find out a topographic map and the geologic map, respectively, which can be used to determine the location of the bridge, bridge length, structural type, as well as the span length ratio. Geotechnical survey, underground water level, including the soil experiment, and hydro technical survey investigation on cross-sectional river shapes (in case of constructing a bridge that will cross a river), level of tide (in case of building a bridge in a lake), water level, and navigation ships, should be carried out to provide information for design and construction of the bridge foundation. Additionally, meteorological survey, seismic survey forcing on seismographic record and earthquake disaster records and, investigating on records of wind speed, rainfall, snowfall, and air temperature, should also be performed [2].

Nevertheless, when planning for a bridge, the location and structural type should be decided according to the geology, route alignment, crossing object, topography, meteorology, and other external conditions. Geometric design for bridge structures includes the graphic design, vertical design, horizontal design, intersections, design of geometric cross sections, and various design details. The goals of geometric design are to increase the economy of facilities, structural safety, serviceability, and structural esthetics, while reducing their environmental impacts.

Horizontal Layout. First and foremost, the location of the bridge location has to be decided. Normally, small bridges and the culverts and has to follow the direction of the main road. By factoring the curves and hydrology on the main road, the bridges can be designed as skewed or curved bridges. For large medium bridges, however, the bridge location should be considered according to the main route direction if possible, and the overall consideration of both bridge and road is essential. A straight channel with good geological conditions and stable water flow will be selected. Additionally, easement curve, the horizontal curve radius, super elevation and broaden, and set-up of the speed-change lanes should be designed according to the specifications of the design.

 Longitudinal Elevation. The bridge longitudinal design involves, the number of spans, the bridge elevation, the total span length, the longitudinal slope, the burial depth of the foundation, etc. The total length of the bridge should be calculated in line with hydrological conditions. In designing a bridge, the design flood discharge has to be factored in, the raft, the vessels and the drift ices, and other drifting objects in the water should be able to pass through the bridge. Adverse change of the waterway due to the excessive compression of the riverbed has to be ignored. The river-bed erosion or scouring that can affect the foundations of the bridge should be carefully checked and avoided in the design.

Number of Spans. For a long bridge, the overall length is normally segmented into many spans. The number of span will not only affect the constructional issues and esthetic nature, but also the overall cost of the bridge to a greater degree. For instance, a larger span length will bring about a small number of span and then lowers the cost of the foundations, but the cost of the superstructure will appreciate. On the other hand, a larger span number and smaller span length will lead to a reasonable low cost of the bridge superstructure and high cost of the substructure. Therefore, appropriate bridge span numbers should be verified on the basis of the most economical design putting into consideration both bridge substructure and superstructure. On the overall, the determination of the span numbers for large span and medium span bridge is a huge problem and should be resolved according to the hydrologic condition, geological conditions, serviceability, economic efficiency, bridge location, and environment.

Transverse Cross Section. The bridge cross section is mainly determined based on the bridge structural type and the bridge width. The bridge width is designed on the basis of the traffic demand and generally taken as the same as the road width that the bridge is located at. The bridge clearance limit (beyond the deck) is normally acknowledge by the significance of the bridge and the design speed of the highway [4].

 Bridgesdesign methods. The design methods used for bridges are Allowable stress design [ASD], Load Factor design [LFD], and Load and resistance factor design [LRFD][14]

Allowable Stress Design (ASD), also known as Working Stress Design (or WSD), is the oldest of the three design codes mainly used for bridges in the United States in recent times. The basic design philosophy of this method is that the maximum stress in a structural member is always smaller than a certain allowable stress in bridge working or service conditions. The allowable stress of a material determined according to its nominal strength over the safety factor. Among three of them, ASD is the most simplistic. The ASD method of design utilizes unfactored loads which are combined to generate a maximum effect in a member. The maximum load or combination of loads cannot be greater than the allowable (or working) stress of the material. The allowable or working stress is obtained by taking the strength of the material and taking an appropriate factor of safety that is greater than unity. The allowable stress Design or working stress design is given as

ΣDL + ΣLL ≤ RU / FS

where:
DL = Dead loads applied to the component under consideration
LL = Live loads applied to the component under consideration
Ru = Ultimate capacity of the component under consideration
FS = Factor of safety > 1.0

It is worthy to note that loads other than dead load and live load have been exempted from the above equation for simplicity. However, they are also included in ASD, as applicable. The main advantage of ASD is that: ASD has an inherent simplicity. Because it does not have to do with the use of load factors or resistance factors, the computations are relatively simple. The disadvantages are that in ASD, no consideration is given to the fact that various types of loads have different levels of uncertainty. For instance, the dead load of a bridge can be estimated with a high degree of accuracy. But, earthquake loads acting on bridges cannot be estimated with the same degree of accuracy and confidence. Despite that, dead loads, live loads, and environmental loads are all treated equally in ASD. So there is inadequate account of variability. Apart from that, because the factor of safety applied to the resistance side of the inequality is based on experience and judgment, consistent measures of risk cannot be determined for ASD. In other words, factor of safety is subjective. Or it cannot give a true safety factor against failure. Additionally, there is no risk assessment based on reliability. And stress is not a good measure of resistance. [2]

Load Factor Design (LFD) was introduced several years ago in a bid to refine the ASD philosophy in reinforced concrete design. LFD uses loads multiplied by load factors and load combination coefficients, which are mainly greater than unity. The factored loads are added to produce a maximum result in a member. Load factors vary by type of load and reflect the uncertainty in estimating magnitudes of different types of loads. In LFD, uncertainty is also taken care of in the resistance side of the inequality. The resistance side is multiplied by a factor, phi (φ), which is normally less than unity in order to take care of the variability of workmanship, material properties, and structural dimensions. The combination of all the loads cannot be greater than the strength of the material multiplied by a reduction factor less than unity. The equation below represents LFD design. However, it is worthy to note that loads other than live load and dead load have been exempted from the equation for simplicity, but they have to be taken into consideration when designing with LFD, as applicable [2][3].



Where:

γ = Load factor applied to all loads

βDL = Load combination coefficient for dead loads
DL = Dead loads applied to the component under consideration

βLL = Load combination coefficient for live loads
LL = live loads applied to the component under consideration

φ = Reduction or resistance factor
Ru = Ultimate capacity of the component under consideration

The main advantages of Load Factor Design (LFD) are: In LFD, a load factor is applied to each load combination to account for the
relative probability that a specific combination of loads would happen
simultaneously.
 In LFD, consideration is given to the fact that various types of loads have
different levels of uncertainty. For instance, it can be estimated that the dead load of a bridge can be with a higher degree of accuracy than the live loads. Therefore,
the load combination coefficient for live load is greater than that for dead load. The main disadvantages of Load Factor Design are that LFD is not as simple to use as Allowable Stress Design. And load factor design does not achieve relatively uniform levels of safety. Presently, ASD design method is still in use in the bridge design specifications in Japan. [2].

Whereas Load and Resistance Factor Design (LRFD) method is the latest advancement in bridge structures design practice. LRFD is a design method by which applicable failure and serviceability conditions can be analyzed putting into consideration the uncertainties associated with loads by using load factors and material resistances by considering resistance factors. The LRFD design method is similar to Load Factor Design. On the load side of the inequality, LRFD uses load factors but not load combination coefficients. The sum of the factored loads, termed “limit states” in LRFD, cannot be greater than the resistance of the material multiplied by a resistance factor that is less than or equal to unity. Several load combinations are included for service, fatigue and fracture, strength, and extreme considerations.
The resistance side of the LRFD inequality is similar to that of Load Factor Design, although resistance factors differ from those used in Load Factor Design. The following relationship represents LRFD design. Remember that for simplicity loads apart from live load and dead load have been excluded from the equation, but they have to be included when designing with Load and Resistance Factor Design method, when applicable.



Where:

γDL = Load factor for dead loads

 DL = Dead loads applied to the component under consideration

γLL = Load factor for live loads

 LL = Live loads applied to the component under consideration

ϕ = Resistance factor

 Rn = Nominal resistance or strength of the component under consideration

The main advantages of Load and Resistance Factor Design are that: LRFD achieves relatively uniform levels of safety for different limit states and material types to the extent possible. In both loads and resistance, LRFD accounts for uncertainty and variability. LRFD provides more consistent levels of safety in the substructure and superstructure (foundations not included) as both are designed using the same loads for targeted or predicted probabilities of failure. That is to say it has uniform level of safety. And risk assessment is based on reliability theory. On the other hand, the main limitations of LRFD is that, availability of statistical data and probabilistic design algorithms is required to meet individual situations that demands rigorous methods for developing and adjusting resistance factors. Resistance factor varies.

Bridge designers who are familiar with the use of Load Factor Design code generally acknowledge many similarities when learning the LRFD design code. While load and resistance factors differ for LRFD as compared to LFD, many procedures for determining material strengths and design loads are the same. LRFD is similar to LFD in the sense that the uncertainty is accounted for on both sides of the inequality. However, the major advantage of LRFD over LFD is that LRFD is based on probability. LRFD was developed based on a specific reliability index that is aimed at a specific probability of failure. The differences in how load factors are applied in LRFD and in LFD are important, but perhaps the greatest difference between LRFD and LFD is that reliability theory was used in LRFD to obtain the load and resistance factors. The load and resistance factors were statistically “calibrated” in a bid to arrive at a more ideal level of safety for different limit states and types of materials. Although, ASD design is the current design specification in Japan, the LRFD method is also used for designing the Tokyo Gate Bridge in Japan [2][4]

Load resistance or Design loads of bridges**.** There are transient and permanent loads. Transient loads defined as forces and loads that are varying over a short time interval. A transient load will not remain indefinitely on the bridge. This include vehicular live load and their secondary effects including dynamic load allowances, centrifugal force, braking force, and live load surcharge. Besides that, there are force effects due to uniform temperature and temperature gradient, pedestrian live loads, force effects due to settlement, winds load on structure, water load and stream pressure, friction forces, wind on live load, vehicular collision force, earthquake load, ice load, and vessel collision forces [9][10].

Whereas permanent load is defined as forces and loads that are either constant or varying over a long period of time upon completion of construction. Examples are dead load of structural components and nonstructural attachments, dead load of wearing surfaces and utilities, horizontal earth pressure loads, downdrag forces, earth surcharge load, vertical pressure from dead load of earth fill, force effect due to shrinkage, secondary forces from post-tensioning, force effect due to creep and miscellaneous locked-in force effects due to contraction process[11][12].

Different loads affecting on the bridge**.** Correct identification of the load to be considered when designing and constructing a bridge is very important. There have been bad experiences in the world that cause the collapsing or failures of bridges or later correction were done to make it suitable to use. For example, the millennium bridge -London is one of a kind that needed modifications after construction because of vibration problem. [14]

#### Dead Load: This is the self-weight of the structure or the bridge elements. Dead load is the permanent weight of all structural and nonstructural parts of a bridge, including the deck slab, parapets, stiffeners, sidewalks, utility lines, gates, guardrails, highway signs, a concrete road surface. and other equipment attached. It also includes the weight of components that will be added in the future, such as wearing surface overlays. In addition to the self-weight of the structure, there are other types of loads such as superimposed load. Weights other than the own weight of the structural elements of the bridge can be referred to be superimposed dead loads. Leveling concretes, finishing concretes, concreting fillings, etc, can be considered as superimposed dead loads. The load is the first design load to be calculated in the design of bridge. Dead load can be estimated from the material’s density table 1.

|  |  |
| --- | --- |
| Materials | Density (Kg/m3) |
| Concrete (Normal Weight) | 2400 |
| Concrete (Lightweight) | 1775 – 1925) |
| Steel | 7850 |
| Aluminum Alloy | 2800 |
| Wood | 800-960 |
| Stone Masonry | 2725 |

Table 1.

Dead load for wearing surface normally asphalt and utilities like lighting, pipes, etc. Asphalt surface may be thicker than designed and may get laid on top of old layer over and over again. The density of asphalt laying material =2250kg/m3. The average thickness of Asphalt on bridge = 9cm. [9]

Live load is the second type of load on the bridge. It is moving load on the bridge throughout its length. The moving loads are Pedestrians, vehicles, etc. but it is difficult to select one vehicle or a group of vehicles to design a safe bridge. According to Indian road congress, there are three classes of vehicles load. And they are class AA loading, class A loading, and class B loading. Class AA Loading is considered when designing a new bridge especially heavy loading bridges like highway bridges in industrial areas, cities, etc. In class AA loading normally two types of vehicles are considered, Wheeled type and Tracked type. While in Class A Loading, this type is applied in the design of all permanent bridges. It is considered as standard live load of a bridge. When a bridge is designed using class AA type loading, then it must also be checked for class A loading. Whereas class B Loading referred to be a light loading. It is used to design temporary bridges like Timber Bridge. [6]

The third type of load is the Impact load. This type of load on bridge is because of sudden loads which occurs when the vehicle is moving on the bridge. When the wheel is in motion, the live load will change periodically from one wheel to another which brings about the impact load on the bridge. When designing the bridge, to consider the impact loads, an impact factor is put into consideration. Impact factor is a multiplying factor which depends upon many factors such as the velocity of vehicle, span of bridge, weight of vehicle, etc.

The fourth type of load is the Wind load, which is also an important factor in the design of a bridge. Wind loads are horizontal loads. For long span bridges, wind load is taken into consideration in the design of super structure. And for medium span bridges, wind load is to be considered for substructure design. But for short span bridges, wind load can be ignored. Wind load on the structure are of two type. The Wind pressure on the structure on the structure itself and wind pressure on the vehicles on the bridge, in which the load is transferred to the bridge superstructure. Wind loads are applied as static horizontal load. It is important to note that for low and small bridges, wind load typically does not control the design. Wind tunnel test has to be carried out to find out the aerodynamic effect or turbulence of the wind on the structure. Dynamic Analysis has to be carried out the dynamic effect of flexible long-span bridge under the wind [12].

The fifth type of load is the longitudinal forces are caused by accelerating or braking of a vehicle on the bridge. When the vehicle accelerates suddenly or stops suddenly it induces longitudinal forces on the bridge structure more especially on the substructure. So, it is recommended that when designing a bridge 20% of live load should be taken into consideration as longitudinal force [5].

Another type of force that is worthy of consideration is the Centrifugal Forces. If bridge is to be built on horizontal curves, then the movement of vehicle along curves will bring about centrifugal force on to the super structure. Because of this design should be done for centrifugal forces. Additionally, when a bridge is to be constructed across a river, some part of the substructure is submerged by water. The water current causes horizontal forces on the submerged portion. The forces caused by water currents are zero at the bed level or at the bottom water level and maximum at the top of water level. Water loads is typically considered in the design of substructures such as piers, foundation and abutment. Water load can be categorized into, buoyancy (vertical uplifting force), static pressure (acting perpendicular to all surfaces), and stream pressure (acting in the direction of the stream) [12].

Besides, thermal stress are also forces that is worthy of consideration. Thermal stresses are caused as a result of change in temperature. When the temperature is very low or very high they induce stresses in the bridge elements especially at the deck joints and the bearings. These forces are tensile in nature so, concrete cannot withstand against this because cracks will be formed. To overcome this, additional steel reinforcement perpendicular to main reinforcement should be made available. Expansion joints are also made available. Furthermore, Seismic Loads is also another type of load that needs consideration when building a bridge in an earthquake zone or seismic zone. Earthquake load induce both horizontal and vertical forces during earthquake. The amount of stress mounted on is mostly dependent on the self-weight of the structure. If weight of structure is more, larger forces will be exerted. Earthquake load are horizontal load. The magnitude of earthquake is characterized by the return period. Small return period for instance 50 years is a minor earthquake, whereas large return period, for instance 500 years is a strong earthquake. For large earthquakes, which rarely occur, the bridge structure is allowed to suffer significant structure damage but must not collapse. But for small earthquakes which is most likely to occur, the bridge should still be in an elastic range, that is there should be no structural damage. Earthquake load must be considered for structures in certain zones. In addition to the live loading described above, fatigue live load need consideration. Fatigue is a process of material failure due to repeated applications of a load. When applied infrequently, these loads would cause no lasting effects, but when applied frequently, they can result in failure. When the load is cyclic, the stress level that results in failure can be less than the material yield stress. The effects of fatigue are based on the following considerations: The magnitude of the stress range, The quality and type of the structural detail, and the number of cycles of this stress range. Repeated unloading and loading of live loads can leads to fatigue in bridge structures. Two factors such as the magnitude of the load and frequency of occurrence necessitate fatigue load [5][8].

 Structural design and drawings. The structural design for a modern bridge should be done in line with existing local design codes, based on method that is theoretically valid and experimentally verified, or other recognized knowledge base. In designing a bridge, some important points have to be considered and they include: (i) the probability of bridge structural members that can collapse; (ii) inspection facilities that are required to conduct in-service inspections, or in case of accidents; and (iii) Likely maintenance method for bridge structures. For elements that are likely to be replaced in the bridge maintenance stage shall be well planned in advance to ensure ease of maintenance and reliability. The design drawing has to do with the papers and other materials such as computer drawing prepared for providing reference information (such as the construction condition, and other matters that related to manufacturing and construction) for structural analysis, bridge construction, and maintenance during the service stage. For highway bridges, various temporary elements are often installed during the construction but lack of those information may result to responses that are inappropriate during inspection and maintenance work. The information that should be contained in a design drawing is as follows: Bridge name, Route name and bridge location, Name of the Engineer, Date of design, Major design conditions such as: Bridge classification, Topographical, Load condition, Material condition, geological and ground conditions, Manufacturing and construction conditions, Design outline, Maintenance conditions, Other relevant matters. Moreover, as earlier said, a good bridge design should be both esthetics and functionality. Visual design elements of bridges are form (three-dimensional), shape (two-dimensional), line (one-dimensional), texture and color. The appropriate arrangement of the visual design elements leads to the order, balance, proportion, harmony, contrast, rhythm, unity scale, illusion, etc. From the historical view point of esthetic bridge design, the requirements for an esthetic bridge design are: Expressiveness, Selection of the most artistic form in consideration of economy, Scale and proportion, Symmetry, Simplicity and continuity, Conformity with environment, Harmony and contrast, Order and balance, Proper combination of materials. Esthetic design main goals should always be factored throughout the design process by which those who design have to insist on developing the best design answer for the above mentioned design requirements [14].

CSiBridge is a software for modeling, analysis and design meant for the engineering of bridge structures. It is meant for the engineering of concrete and steel bridge systems. CSiBridge offers a single user interface to perform modeling, analysis, design, scheduling, load rating, and reporting. The software offers practical intuitive, and productive computational tool for bridge engineering. It can use code-specific design processes to concrete box girder bridge design, if the superstructure includes Precast Concrete Box bridges that has a steel I-beam. The simple and easy way with which these tasks can be done makes CSiBridge software the most productive bridge design package in the industry. Design using CSiBridge is based on design requests, load cases, load patterns, and load combinations. The output of the design can then be shown graphically and printed using a customized reporting format. It worthy to note that the design of bridge superstructure is a complex topic
and the design codes cover many aspects of this process. The software is a tool to
help the user with that process.

Another design and modeling software used is LEAP Bridge. It is an important concrete bridge analysis and design software used by engineers worldwide. It offers seamless parametric bridge modeling and superstructure and substructure analysis. LEAP Bridge software is developed by engineers who have expert knowledge of design methods and code specifications with top-quality bridge engineering technology delivering experience. LEAP Bridge Steel is a comprehensive 3D steel bridge design and rating application. It gives advanced physical 3-Dimension bridge modeling, design, analysis, and load rating of steel bridges, following American Association of State Highway and Transportation Officials (AASHTO) Load And Resistance Factor Design (LRFD) specifications. [6].

**Conclusion**

The structure of a bridge is the province of the engineer and that beauty is fully attained only by the addition of [architecture](https://www.britannica.com/topic/architecture). From the standpoint of pure engineering, bridges make the most efficient possible use of good and superior materials are by design beautiful. The engineers must be innovative and think very well on how to make the structure beautiful. Bridge design that best serves the public interest to be economical, efficient, and elegant as is safely possible.

Despite the different types of bridges, they all need to be tight and safe at the abutments and foundations. In designing a bridge, the durability, reliability, environmental compatibility, fitness to the purpose of use, securing of the construction quality, safety of structures, ease of maintenance, and economy have to be taken into cognizance. Correct identification of the load to be considered when designing and constructing a bridge is very important. Besides, the design methods play a crucial role. The drawing of the bridge is also key.

The design and modeling of a bridge can be achieved using of software such as CSiBridge or LEAP Bridge.

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