COMPUTATIONAL DESIGN AND STRUCTURAL ANALYSIS OF BRIDGE FRAMEWORKS WITH STAAD.PRO

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Abstract : Bridge is a construction through which one passes through an obstruction leaving the path open on the other side. The passage required can be of a road, a railway, of pedestrians, of a canal or a pipeline. The barrier that is to be crossed can be a river, a road, rail or a valley. That is to say, bridge is a construction that supports the road traffic or other moving loads above a depression or road block like channel, road or railway. A bridge is a construction aimed at overcoming a physical obstruction made up of a low ground or a stream or a river, to allow passage over the obstacle.The superstructure 20m transverse connect comprises 4 nos precast pre-focussed on solid support 0.15m thick thrown in situ RCC and beam with 350mmx350mm and 350mmx450mm of bridge is designed and analyzed in this project. The varieties of designs are numerous and each of them is purposely designed and applicable to various circumstances. Bridge designs are different based on the purpose of the bridge, the type of terrain where the bridge is built and held, the material used to create it, and the amount of money one has to build it. In this we will design the girder bridge using a software called staad pro.

1. INTRODUCTIN

A bridge is a structure providing passage over an obstacle without closing the way beneath. The required passage may be for a road, a railway, pedestrians, a canal or a pipeline. The obstacle to be crossed may be a river, a road, railway or a valley.

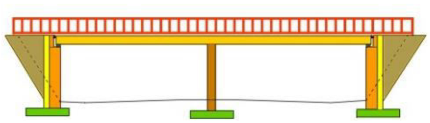


Fig 1.1: Bridge

1.1 Components of bridge

The bridge structure comprises of the following parts.

- **Superstructure or Decking**

  This includes slab, girder, truss, etc. This bears the load passing over it and transmits the forces caused by the same to the substructures.

- **Bearings**

  The bearings transmit the load received from the decking on to the substructure and are provided for distribution of the load evenly over the substructure material which may not have sufficient bearing strength to bear the superstructure load directly.

- **Substructure**
  This comprises piers and abutments, wing walls or returns and their foundation.

Piers and Abutments These are vertical structures supporting deck/bearing provided for transmitting the load down to the bed/earth through foundation.

Abutments

Fig 1.2: Full height integral abutments

- These are generally used for the shorter spans (< about 20m).

Fig 1.3: Integral abutments with piled foundations

- Usually incorporate steel H piles in a single row; the H piles are orientated so that bending occurs about their weaker axis. These abutments are suitable for the larger span decks.

Fig 1.4: Integral abutments with spread footings

- Integral abutments with spread footings should only be used where settlement due to consolidation of founding strata is minimal. Where decks exceed 60 meters long or have skews exceeding 30° then movement joints and bearings usually need to be provided.

Geometric Considerations:

Usually the narrow bridge is cheaper in the open abutment form and the wide bridge is cheaper in the solid abutment form. The exact transition point between the two types depends very much on the geometry and the site of the particular bridge. In most cases the open abutment solution has a better appearance and is less intrusive on the general flow of the ground contours and for these reasons is to be preferred. It is the cost of the wing walls when related to the deck costs which swings the balance of cost in favor of the solid abutment solution for wider bridges. However, the wider bridges with solid abutments produce a tunneling effect and costs have to be considered in conjunction with the proper functioning of the structure where fast traffic is passing beneath. Solid abutments for narrow bridges should only be adopted where the open abutment solution is not possible. In the case of wide bridges, the open abutment solution is to be preferred, but there are many cases where economy must be the overriding consideration.

Wing walls and Returns These are provided as extension of the abutments to retain the earth of approach bank which otherwise has a natural angle of repose.

Foundation This is provided to transmit the load from the piers or abutments and wings or returns to and evenly distribute the load on to the strata. This is to be provided sufficiently deep so that it is not affected by the scour caused by the flow in the river and does not get undermined. While the above mentioned are structurally operational parts, for safety hand rails or parapets, guard rails or curbs are provided over the decking in order to prevent vehicle or user from falling into the stream or for the separation of traffic streams.

1.3 Classification

Bridges may be classified in many ways, as below.

According to the flexibility of superstructure as fixed span bridges or movable bridges.

- Fixed span superstructure

In case of fixed span superstructure, the superstructure remains in a fixed position and most of the bridges are of this category.

- Movable span bridges

In case of movable span superstructure, the superstructure is lifted or moved with the help of some suitable arrangement. According to the position of bridge floor relative to the formation level and the highest flood discharge as deck bridges, through bridges or semi through bridges.

- **Deck bridges**

Deck-type bridges refer to those in which the road deck is carried on the top flange or on top of the supporting girders. The deck slab or sleeper may cantilever out to some extent beyond the extreme longitudinal girder.

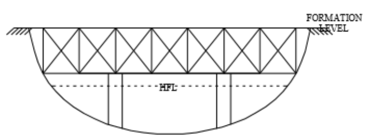


fig 1.5: Deck Bridge

- **Through bridges**

In the through type bridges, the decking is supported by the bottom flange of the main supporting girders provided on either side.

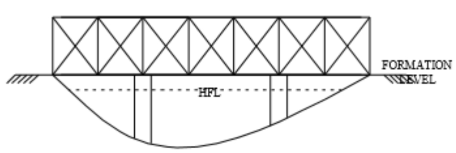


Fig 1.6: Through Bridge

- **Semi through bridges**

The semi-through bridge has its deck midway and the deck load is transmitted to the girder through the web of the girder. In this also, the main girders are on either side of deck.

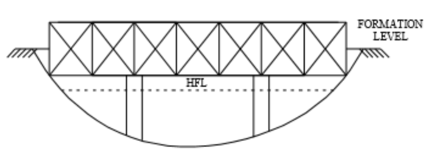


Fig 1.7: Semi-through Bridge

According to the inter-span relations as simple, continuous or cantilever bridges.

- **Simply supported**

Generally, width of bridge is divided into number of individual spans. For each span, the load carrying member is simply supported at both ends. The plate girder and truss girders are used as this type of bridges. They are suitable at places where uneven settlements of foundations are likely to take place.

- **Continuous**

In continuous bridges spans are continuous over two or more supports. They are statically indeterminate structures. They are useful when uneven settlement of supports does not take place. In continuous bridges the bending moment anywhere in the span is considerably less than that in case of simply supported span. Such reduction of bending moment ultimately results in the economic section for the bridge. In continuous bridges the stresses are reduced due to negative moments developed at pier or supports. Thus, continuous span bridges have considerable saving compared to simply supported bridge construction. Following are the advantages of RCC continuous girder bridges over simply supported girder bridges.

- As the bearings are placed on the centreline of piers, the reactions at piers are transmitted centrally.
- It is found that the continuous girder bridge suffers less vibration and deflection.
- The continuous girder bridge requires only one bearing at each pier as against two bearing for simply supported girder bridge.
- The depth of decking at mid span is reduced and it may prove to be useful for over bridges where headroom is of prime consideration.
- The expansion joints required will be less.

- There is reduction in cost as less quantity of concrete and steel are required. Following are the disadvantages of RCC continuous girder bridges over simply supported girder bridges.
- The design is more complicated as it is a statically indeterminate structure.
- The detailing and placing of reinforcements are to be carried out with extreme care.
- The placing of concrete and removal of formwork are to be executed carefully in proper sequence.

- **Cantilever**

A cantilever bridge is formed of cantilevers projecting from supporting piers. The ends of a cantilever bridge are treated as fixed. A cantilever bridge combines the advantages of a simply supported span and a continuous span. For long spans and deep valleys and at places where it will not be practicable to use centring, cantilever bridges are more suitable. They are suitable in case of uneven settlement of foundation. The construction of a cantilever bridge may either be of simple type or of balanced type.

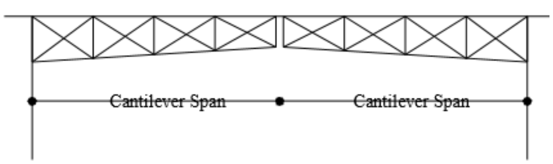


Fig 1.8: Cantilever Bridge with simple construction

In case of cantilever bridge with balanced type of construction, hinges are provided at the points of contra flexure of a continuous span and an intermediate simply supported span is suspended between two hinges.

Cantilever Bridge with simple construction

Fig 1.9

According to the form or type of superstructure as arch, beam, truss, slab, rigid frame or suspension bridges.

- Slab
- Beam

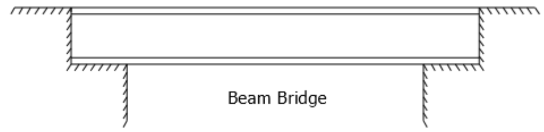


Fig 1.10

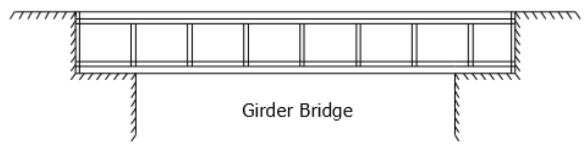


Fig 1.11

- Girder
- Truss

The girder/beam as well as the truss can be made up of timber, steel or concrete, or can be made up of combination of steel and concrete.

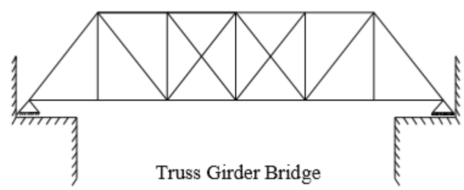


Fig 1.12

- **Arch**

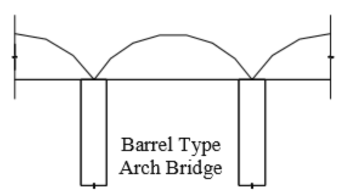


Fig 1.13

- **Suspension**

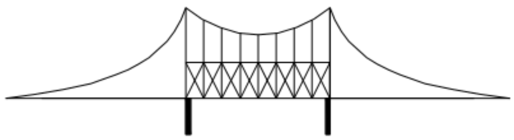


Fig 1.14

Suspension bridges are made up of high tensile steel cables strung in form of catenaries to which the deck is attached by steel suspenders, which are mainly made up of steel rods/members/cables. The decking can be of timber, concrete or steel spanning across the stiffening girders transmitting load to the suspenders.

- **Cable stayed**

  Cable-stayed bridges are similar to the suspension bridges excepting that there will be no suspenders in the cable-stayed bridges and a number of these can be of masonry, concrete or steel.

Various economical span ranges for these types generally adopted are:

Arch: For small spans of 3 to 15m in masonry, steel arch up to 519m and concrete arches up to 305m spans.

Slabs: Up to 9m.

Girders and beams: 10 to 60m (exception up to 250m in continuous construction). Trusses: 30 to 375m simply supported and up to 550m with cantilevered combination. Suspension Bridges: Over 500m up to 1400m.

Cable Stayed: 300 to 600m.

According to the materials of construction used for superstructure as cement concrete, prestressed concrete, steel, masonry, iron, timber or composite bridges. The earliest form of materials used for construction of bridges was first stone and later brick. The masonry bridges are used for short spans and according to availability of material and skilled labour. They are mainly of arch type of bridges. The next form of construction was Timber Bridge in which timber was used for spanning the gap and also for supporting the beams. Timber bridges are used for short spans, light loads and for use as temporary and unimportant bridges. With the invention and development of concrete, bridges are being built entirely with concrete, either reinforced or prestressed or a combination of both for superstructure. Many combinations of above types are also possible.

2. LITERATURE REVIEW

Before we were able to start the design and methodology phase of our project, we had to research and identify the different components of a typical highway overpass. Along with the components of an overpass, we investigated the site design, constructability, cost influence, and the condition of the current structure.

The subject bridge is the Rt.122 highway overpass which extends over Rt.20. It is located southeast of downtown Worcester, as can be seen in Figure 2.1. Because of its close proximity to the city and the Mass Pike, it is a very heavily trafficked road. It serves a wide variety of motorists from local traffic to tractor trailers. The bridge was built in 1931 during the Great Depression. Since then, it has not had a major rebuild or rehabilitation. Also, the bridge has exceeded its expected service life of 75 years and is due for replacement in the near future. The bridge is built out of very typical materials from that era. It has steel stringers and girders and a cast-in-place concrete deck.

The objectives of this project were to back calculate bridge foundation dynamic stiffness and identify bridge foundation type using dynamic measurements of a bridge substructure, and to monitor bridge substructure conditions over time by repeating dynamic tests at preselected time intervals or after the occurrence of a natural event such as an earthquake or flood. The project objectives were met by performing field vibration tests before and after simulated earthquake and scour damage to actual bridge foundations, modal analysis, finite element modelling (FEM), structural parameter estimation, and a new dynamic response system identification technique known as the HHT.

This Chapter discusses the details of four bridge bents in three bridges with different foundation conditions and types that were field tested in Texas during 1996 and 1997. All four bridge bents were first tested in their existing, undamaged states. Because one of the bridges was demolished during the field research, two bents could be tested in an undamaged state, and then in a simulated scour state, and finally in a simulated earthquake damage state. The simulated foundation damage conditions were meant to represent the effects of scour and earthquake events on bridge foundations, and the selected foundation types are representative of typical highway bridge foundation configurations in the United States.

Chapter discusses the dynamic testing of the four bridge substructures including instrumentation, test procedures, and data processing used in the field modal vibration tests of the four bridge bents. A specially modified large, truck-mounted geophysical vibrator (a Vibroseis) owned by the Geotechnical Engineering Centre of the University of Texas at Austin was used primarily as the vibration source. The Vibroseis consists of a large truck with a gross weight of about 22,246 kilograms (kg) (49,000 pounds (lb)) with a servo-hydraulic vibrator mounted on it. Vertical dynamic forces up to 31,780 kg (70,000 lb) over a frequency range from 1 to 120 hertz (Hz) may be produced with the Vibroseis. Seismic accelerometers were attached to various locations on the tested bridge bents to record bridge dynamic responses under forced vibrations. A personal computer (PC)-based four-channel dynamic signal analyser served as the central vibration control and measurement unit.

Chapter presents the experimental findings in terms of foundation condition and type identification. Dynamic characteristics of each bridge substructure such as natural frequency, damping ratio, and mode shape were extracted from the field data and interpreted by modal analysis techniques.

Chapter discusses the results of modelling and structural parameter estimation and system identification techniques that were used to produce engineering information such as lateral, vertical, and rotational resistance of the bridge foundations. In terms of theoretical analysis, three-dimensional (3-D) FEMs for all four tested bridge bents were accomplished by using a commercial software package. The 3-D FEMs consist of super-soil-structural elements that can represent the bridge foundation conditions and types. Based on the 3-D FEMs, two-dimensional (2-D) FEMs for the four tested bridge bents were established because the current structural parameter estimation and system identification program used in this project is available for 2-D models only.

Chapter discusses the HHT and results of its application to the two bents that were tested in undamaged, simulated flood, and simulated earthquake states. The HHT method is designed to identify instantaneously at points in time the reduction in natural frequency associated with local damage from otherwise linearly elastic response data for the rest of a structure that are often unidentifiable in conventional modal testing and analysis.

Chapter explores the possibility of incorporating the dynamic bridge substructure testing and analysis results into BMS. This step will be taken in the future to provide practical benefits to departments of transportation (DOT) and the public with research in improved safety and reduced risk of bridge substructure failure.

3. METHODOLOGY

3.1 Loads

The Designer must consider all loads that are expected to be applied to the structure. These loads shall include but not be limited to permanent loads, live loads, water loads, construction loads, wind loads, ice loads, earthquake effects, earth pressure, vehicular collision force, force effects due to superimposed deformations, friction forces and vessel collision forces. These loads shall be in accordance with Section 3 of the Governing Specifications, unless specified otherwise within this document.

3.2 Permanent Loads

Permanent loads shall include dead loads due to the weight of all structural components including future wearing surface, earth surcharge (as applicable) and horizontal earth pressure.

The Designer shall use a load of 15 PSF for permanent deck forms. When girder or beam spacing 14 feet or greater are utilized, the designer shall determine if the 15 PSF for permanent deck forms needs to be increased. All structures shall be designed for a future wearing surface of 25 PSF. Unless a more refined analysis is performed to calculate active earth pressure, the Designer shall use a minimum of 40 PCF for equivalent fluid pressure.

3.3 Live Loads

All structures shall be designed for the HL-93 live load. Fatigue load frequency, ADTTSL (number of trucks per day in one direction in a single lane over the design life-75 years), shall be provided to the Designer by the Bridge Project Manager. Otherwise, a factor, provided by the Bridge Project Manager, shall be used to reduce the ADTT (number of trucks per day in one direction averaged over the design life-75 years) to a single lane.

The dynamic load allowance may be reduced for components other than joints, if justified by sufficient evidence, in accordance with the provisions of AASHTO 4.7.2.1, Vehicle-Induced Vibrations). Approval by the WVDOH is required. The dynamic load allowance can be reduced by 50% for timber bridges and wood components of bridges.

3.4 Ice and Snow Loads

Bridge components subject to ice forces shall be designed for these conditions:

- Q10 elevation
- 32 KSF ice load
- 6 IN ice thickness
- If Q50 > 50,000 CFS, a study to determine the ice forces shall be performed

No special snow loads are required on bridges.

3.5 Earthquake Effects

All bridges in West Virginia are assigned Seismic Performance Zone 1. The Owner shall classify a bridge's importance category for seismic design. These classifications shall be based on the following:

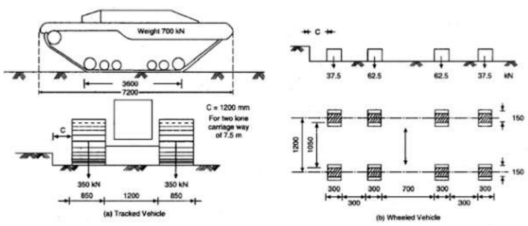
- A bridge may be classified as "critical" at the direction of the Director of Engineering Division. A "critical" bridge shall be designed based on a 2500year return period event.
- All National Highway System bridges are classified as "essential" unless a direct road detour is near the bridge. An "essential" bridge shall be designed based on a 475-year return period event.
- All other bridges shall be designed based on a 50-year return period event.

3.6 Indian Road Congress

- Indian Road Congress (IRC) is the governing body which decides the rules and regulation along with technical details regarding roads, highways, and bridges. The first loading standard in India was published by IRC in 1958 and subsequently reprinted in 1962 and 1963. The metric version was introduced in the second revision published in 1964.
- **IRC Bridge Loading Standards**
- The standard IRC loads specified in IRC: 6-2000 are not changed since 1958 and grouped under four categories as detailed below:

1. IRC Class AA Loading

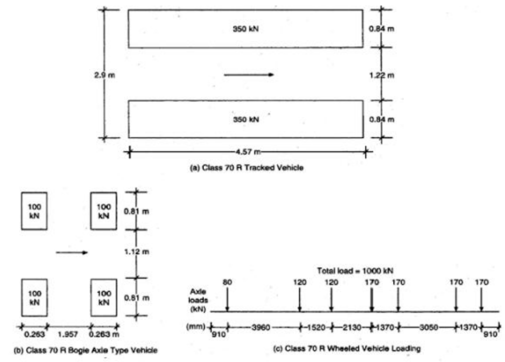
- In this category, two types of vehicles are specified and they are grouped as tracked vehicle and wheeled vehicles. The tracked vehicle simulating an army tank of 700 KN and wheeled vehicle of 400 KN (a heavy army truck) are standardized for the designing of all the bridges located on National Highways and State Highways.



I.R.C. Class AA Tracked and Wheeled Vehicles.

2. IRC Class 70R Loading

- The following vehicles are considered for the design under this category:
- (a) The tracked vehicle of the total load of 700 KN with tracks each weighing 350 KN each
- (b) Wheeled vehicle of the total load of 400 KN with each wheels weighing 100 KN each
- (c) Wheeled vehicle with a train of vehicles on seven axles with a total weight of 1000 KN
- The option (a) might seem to be the same as the tracked vehicle of IRC Class AA. But, it is slightly different from the tracked vehicle of IRC Class AA. In this category of IRC Class 70R, the contact length of the vehicle is 4.87m, the total length of the vehicle from nose to tail is 7.92m and the specified minimum distance between successive vehicles is 30m.
- Similarly, in option (b) it is specified that the total load of 400 KN is distributed equally on each wheel with 100 KN each which is different from the wheeled vehicle of IRC Class AA.
- Option (c) is one more consideration of a vehicle that is taken into account while designing under this category. It is the wheeled vehicle with a train of vehicles on seven axles with loads as shown in the figure which adds up to a total of 1000 KN.



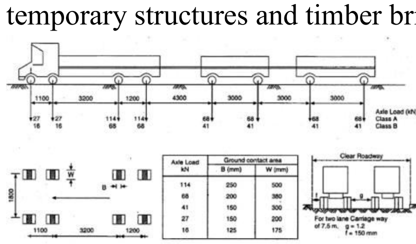
I.R.C. Class 70 R Tracked and Wheeled Vehicles.

3. IRC Class A Loading

- The IRC Class A loading is consists of a wheel load train of a total load of 554 KN. It comprises a heavy-duty truck with two trailers that transmit loads from 8 axles varying from a minimum of 27 KN to a maximum of 114 KN as shown in the figure. This type of loading is recommended for all roads on which permanent bridges and culverts are constructed.

4. IRC Class B Loading

- The loading of this class is similar to the Class A loading except that the axle loads are of lesser magnitude. The total axle loads of this Class are 332 KN with a train of wheeled vehicles on eight axles as shown in the figure.
- This type of loading is adopted for temporary structures and timber bridges.



IRC Class A and B Loading

4. RESULTS

Click on the Add button on the right. Input the "Dead Load" in the Title input box. Select "Dead" in the Loading type selection box. Press the Add button. Click the Close button.

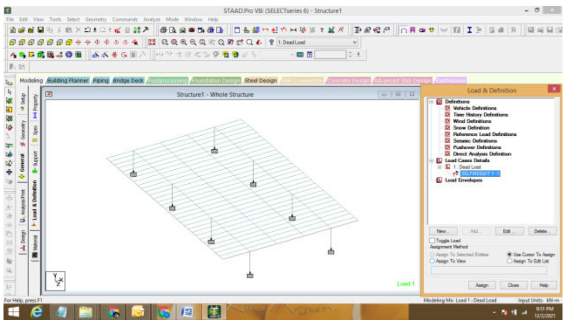


Fig 4.4: adding of self-weight to the dead load

15. Select the newly created 1: Dead Load entry in the data area. Press the Add button. Select the Selfweight item and press the Add button. 37. Click on the Analysis/Print control tab item on the left and press the Add button. 38. Click on the Analyze->Run Analysis menu. Use the STAAD Analysis option and click on the Run Analysis button.

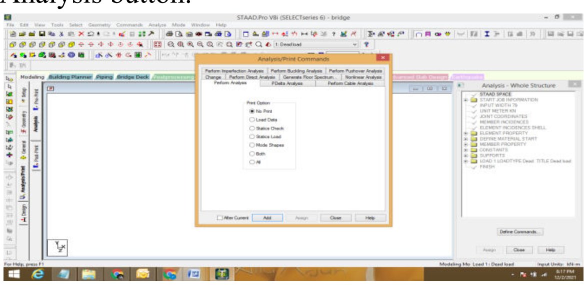
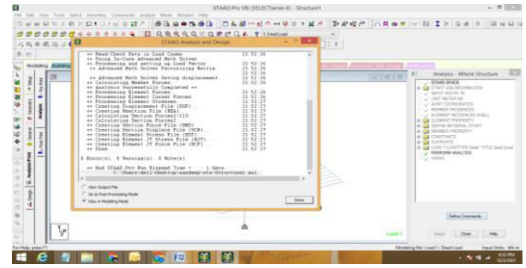
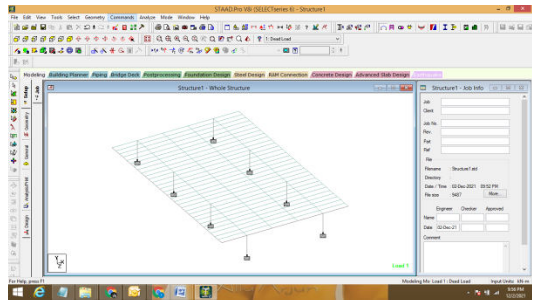


Fig 4.5: run analysis

16. You can look at the bending moment diagram for the bridge by clicking on the Beam>Forces control tab on your left in the Post-Processing mode.

17. You can look at the stress distribution diagram for the bridge by clicking on the Plate control tab on your left. Select the Max Absolute stress type from the Stress Type selection box and click on the Ok button.





Design of deck using beava code:

1. Click on Mode->Bridge Deck Pre-processor menu

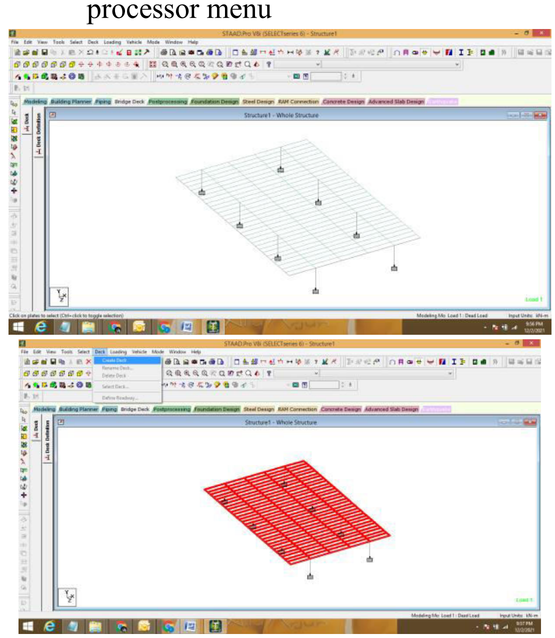
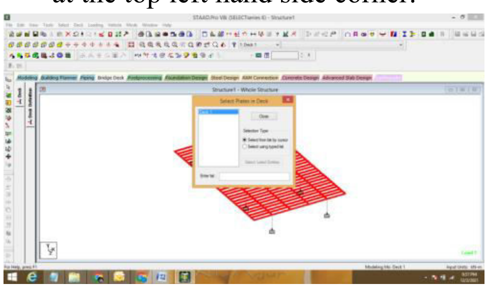


Fig 4.6: creating of deck

2. The first step in STAAD.beava is to generate a deck and define a roadway. The second step is to generate the influence surface and view the influence surface diagrams. The influence surface diagram will give a clear picture of the distribution or stresses, moments, forces, etc. across the bridge as a result of loading a certain place with unit loading. The last step is to use the Load

Generator to generate the desired maximum responses and transfer them into STAAD.pro as independent load cases for further analysis and design.

3. To generate a deck and define a roadway, select the Plates Cursor and select all plates in the model. Click on Deck->Create Deck command in the menu. To accept the default name of the deck click the Ok button. In STAAD.beava, you are allowed to create multiple decks and multiple roadways on a single deck.
4. Click on Deck->Define Roadway menu and click the New button. The next few steps will illustrate the creation of lanes on the Deck 1 that has been created. Using the Nodes Cursor, the user may find out the coordinates of the deck as shown below. The origin of the deck is at the top left hand side corner.



5. CONCLUSIONS

STAAD.pro in combination with STAAD.beava can be used to analyse bridges as per the AASHTO code. STAAD.pro is first used to construct the bridge geometry and STAAD.beava is used to find the IRC load positions that will create the maximum load response. These loads that create the maximum load responses can then be transferred into STAAD.pro as load cases to load combinations for further analysis and design. This manual has demonstrated the design of the steel girders. A similar design approach can be used for design of concrete members, slab elements and foundations.

6. References

[1] IRC 5:1998 Standard specification and code of practice for road bridges- Section I general features of design

[2] IRC 6:1966 Standard specification and code of practice for road bridges – Section II load and stress

[3] IRC 21:1987 Standard specification and code of practice for road bridges- Section III cement concrete

[4] IRC 40 : 1995 Standard specification and code of practice for road bridges- Section IV (bricks, stones and masonry)

[5] IRC 22:1986 Standard specification and code of practice for road bridges- Section VI composite construction

[6] IRC 78:1983 Standard specification and code of practice for road bridges- Section VII formation and sub structure

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