DESIGN OF T-BEAM BRIDGE BY FINITE ELEMENT METHOD AND AASHOT SPECIFICATION

Dr. Maher Qaqish 1, Dr. Eyad Fadda 2 and Dr. Emad Akawwi 3*

1 Associate Professor, College of Engineering, Al-Balqa Applied University, Salt, Jordan
2 Assistant professor at Al-Balqa Applied University-Salt-Jordan
3 Assistant professor at Al-Balqa Applied University-Salt-Jordan

ABSTRACT

A simple span T-beam bridge was analyzed by using AASHTO specifications and Loadings as a one dimensional structure, then a three-dimensional structure was carried out by using finite element plate for the deck slab and beam elements for the main beam. Both models were subjected to 1.5 AASHTO Loadings and at certain locations to produce maximum bending moment and maximum shear. The results were analyzed and it was found that the results obtained from the finite element model are smaller than the results obtained from one dimensional analysis, which means that the results obtained from AASHTO loadings are conservative.

KEYWORDS: T-beam Bridge, Bridges, AASHTO specification, finite element method, AASHTO loading.

1. INTRODUCTION

Many methods are used in designing bridges such as AASHTO specifications, grillage and finite element methods. T-beam bridges are composed of deck slab 20 to 25cm thick and longitudinal beams spaced from 1.9 to 2.5m. A study made by Gerald A. Culham and Amin Ghali [1] indicate that one cross girder at the middle is more effective than two cross girders at the third points and the presence of two cross girders at quarter points in addition to the one at the middle may and may not improve the load distribution and in both cases the change is small. The AASHTO specifications [2] specifies that diaphragms are recommended at midspan for spans up to 15.0m, at third points for spans up to 23m and at quarter points for spans over 23.0 m. The analysis of superstructure is derived from orthotropic plate theory in which the actual structure is replaced by an equivalent continuous structure which has the same average flexural and torsional stiffness as the actual structure [3]. One of the earlier distribution coefficient methods is based upon the analysis of orthotropic plates in which the loads are represented by a harmonic series [4]. The structural properties of the deck bridges are defined in [5]. Al-Foqaha’a [6] studied the recent loading adopted for bridge design in Jordan was carried out [6]. There are different techniques used in designing bridges but the most common are AASHTO [2], finite element method, grillage and finite strip methods [7].

2. METHODS

2.1 Grillage Analysis:

This method is usually used for analysis of bridges based on the consideration of the bridge deck as an elastic continuum in the form of an orthogonally anisotropic plate. Using the stiffness method of structural analysis, it became possible to analyze the bridge deck structure as an assembly of elastic structural members connected together at discrete nodes. There are four distinct techniques which have been found useful by bridge engineers: grillage and space frame analysis, folded plate method, finite element method and finite strip method [7]. The grillage analogy method involves a plane grillage of discrete interconnected beams. The grillage analogy has become popular because of the following reasons:

* Corresponding author. E-mail: maherkakish@yahoo.com
It can be used in cases where the bridges exhibits complicating features such as a heavy skew, edge stiffening and deep hunches over supports.

The representation of a bridge as a grillage is ideally suited to carrying out the necessary calculations associated with analysis and design on a digital computer.

- The grillage representation is conductive in giving the designer an idea about the structure behavior of the bridge and the manner in which bridge loading is distributed and eventually taken to the supports [8]. It is a horizontal grid consisting of the main (longitudinal) and cross (transverse) girders are orthogonally intersecting and is subjected to vertical loads only. Each of the longitudinal girders having flexural stiffness (EI), torsional stiffness (GJ) and length (L). The longitudinals girder are spaced a distance (h) apart and are interconnected by a number of equally spaced transverse beams each of which has flexural stiffness (EL) and torsional stiffness (GJL) [8].

In a grillage analysis, the elements of a grid are assumed to be rigidly connected, so that the original angles between elements connected together at a node remain unchanged. Both torisonal and bending moment continuity then exist at the node point of a grid [9]. Each beam element is assumed to have three degree of freedom at each end. These consist of two rotations and a transverse displacement as shown in Figure (1).

Generally, grillage analysis is the most common method used in bridge analysis. In this method the deck is represented by an equivalent grillage of beams. The finer the grillage mesh, the more accurate the results are. It was found that the results obtained from grillage analysis compared with experiments and more rigorous methods are accurate enough for design purposes. If the load is concentrated on an area which is much smaller than the grillage mesh, the concentration of moments and torque cannot be given by this method and the influence charts described in Puncher [10] can be used. The orientation of the longitudinal members should be always parallel to the free edges while the orientation of transverse members can be either parallel to the supports as shown in Fig. (2). According to CCA [11] the orthogonal mesh is cumbersome in input data but the output moments results Mx, My, and Mxy can be used directly in the Wood-Armer equations as in Hambly [12] to calculate the steel required in any direction.
2.2 Finite Element Method

The finite element method is a well-known tool for the solution of complicated structural engineering problems, as it is capable of accommodating many complexities in the solution. In this method, the actual continuum is replaced by an equivalent idealized structure composed of discrete elements, referred to as finite elements, connected together at a number of nodes. The finite element method was first applied to problems of plane stress, using triangular and rectangular elements. The method has since been extended and we can now use triangular and rectangular elements in plate bending, tetrahedron and hexahedron in three-dimensional stress analysis, and curved elements in singly or doubly curved shell problems. Thus the finite element method may be seen to be very general in application and it is sometimes the only valid form of analysis for difficult deck problems. The finite element method is a numerical method with powerful technique for solution of complicated structural engineering problems. It is mostly accurately predicted the bridge behavior under the truck axle loading \([13]\). The finite element method involves subdividing the actual structure into a suitable number of sub-regions that are called finite elements. These elements can be in the form of line elements, two dimensional elements and three-dimensional elements to represent the structure. The intersection between the elements is called nodal points in one dimensional problem where in two and three-dimensional problems are called nodal lines and nodal planes respectively. At the nodes, degrees of freedom (which are usually in the form of the nodal displacement and/or their derivatives, stresses, or combinations of these) are assigned. Models which use displacements are called displacement models and models based on stresses are called force or equilibrium models, while those based on combinations of both displacements and stresses are called mixed models or hybrid models \([14]\).

Displacements are the most commonly used nodal variables, with most general purpose programs limiting their nodal degree of freedom to just displacements. A number of displacement functions such as polynomials and trigonometric series can be assumed, especially polynomials because of the ease and simplification they provide in the finite element formulation. To develop the element matrix, it is much easier to apply a work or energy method. The principle of virtual work, the principle of minimum potential energy and castigliano's theorem are methods frequently used for the purpose of derivation of element equation.

The finite element method has a number of advantages; they include the ability to \([9]\):

- Model irregularly shaped bodies and composed of several different materials.
- Handle general load condition and unlimited numbers and kinds of boundary conditions.
- Include dynamic effects.
- Handle nonlinear behavior existing with large deformation and non-linear materials.

This method needs more time and efforts in modeling than the grillage. The results obtained from the finite element method depend on the mesh size but by using optimization of the mesh the results of this method are considered more accurate than grillage. Fig (3) shows the finite element mesh for the deck slab and also for three-dimensional model of bridge. The finite element method is a well-known tool for the solution of complicated structural engineering problems, as it is capable of accommodating many complexities in the solution. In this method, the actual continuum is replaced by an equivalent idealized structure composed of discrete elements, referred to as finite elements, connected together at a number of nodes. The finite element method was first applied to problems of plane stress, using triangular and rectangular elements. The method has since been extended and we can now use triangular and rectangular elements in plate bending, tetrahedron and hexahedron in three-dimensional stress analysis, and curved elements in singly

Fig (2): Grillage Mesh Showing Transverse Beams Parallel to Supports.
or doubly curved shell problems. Thus the finite element method may be seen to be very general in application and it is sometimes the only valid form of analysis for difficult deck problems. Tiedman [15] shows the finite element method is a numerical method with powerful technique for solution of complicated structural engineering problems. It most accurately predicted the bridge behavior under the truck axle loading. Qaqish [16] discuss the effect of skew angle on distribution of bending moments in T-Beam bridge. Al Foqaha'a [17] indicates that 50% of the total number of the existing bridges are T-beam bridges. Furthermore, many of these bridges are skew ones due to the alignment of the highway. Alasa'd [18] studied the effect of skew on cast insitu bridges with spans 12, 14, 16, 18 and 20 meters and skew angles 10° through 60°, inclusively with an increment of 10°. Alasa'd [18] used computer program SAP 90 [19] for the analysis of the finite element mesh of the bridge superstructure. For Design purposes Winter [20] and Ministry of public works, code of practice for plain and reinforced concrete [21] are used. Al Mubaydeen [22] find that increasing the skew angle will move the point of Maximum positive moment near to the middle support of the bridge and also increasing the value of Maximum positive moment of the girder for the same span length. In addition to, the shear force near the obtuse corner was decreasing for increasing of the skew angle while near the acute corner it was increasing for all spans. The vertical reaction at the support near the obtuse corner was increasing for increasing the skew angle for all spans with a percent of 8.5%. Heins [23] presented the design of T-Beam bridge. In this study the finite element model was carried out be using STAADPRO 2003 [24].

Fig (3): Three-Dimensional Structures Composed of Finite Plate Elements

2.3 Live Loads

The live loads of the AASHTO specifications [2] consist of standards trucks or of lane loads which consist of a uniformly distributed load and a concentrated load. The maximum truck loading is HS20 and it is designated by the indication HS20-44. This loading consists of a 3-axle vehicle with a total weight of 32.5 tons. Axle loads and dimensions of HS20-44 vehicle are shown in Fig (4). The lane loading as shown in Fig (5) is composed of distributed load plus concentrated loads. The concentrated loads are composed of one load for bending and the other for shear as shown in Fig (2). These concentrated loads are located in certain positions, in addition to the distributed loads to give the maximum bending and shear stresses. Live load stresses due to truck loading (or equivalent lane loading) are increased to allow for vibration and the sudden application of the load.

The increase is computed by the formula:

\[
I = \frac{15}{L} + \frac{24}{38} < 0.3
\]

Where \( I \) = the impact fraction of live load stress. \( L \) = the loaded length in meters.

To encounter the unexpected traffic loadings, these loadings are multiplied by 1.5. Study of axle weight in Jordan is illustrated in (25), (26).

Standard truck or lane loading is assumed to occupy a loaded width of 10ft (3.048m). These loads shall be placed in 12ft (3.65m) wide design traffic lanes spaced across the entire bridge roadway width in number and position required to produce the maximum stress in the member under consideration. The uniform and concentrated load of a lane loading shall be considered to be uniformly distributed over a 10ft (3.048m) width on a line normal to the centerline of the lane. In computing stresses, each 10ft lane loading or single standard truck shall be considered as a unit that can occupy position within its individual traffic lane, so as to a produce maximum stress. Fractional load lane widths or fractional trucks shall not be used. For continuous spans, only one standard H or HS truck per lane shall be considered and placed so as to
produce maximum positive or negative moments. The type of loading used, whether lane loading or truck loading and whether the spans are simple or continuous shall be the loading which produces the maximum stress. Where maximum stresses are produced in any member by loading any member of traffic lanes simultaneously, the following percentage of the resultant live load stress shall be in view of improbable coincident maximum loading:

<table>
<thead>
<tr>
<th>Number of Lanes</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>One or two lanes</td>
<td>100%</td>
</tr>
<tr>
<td>Three lanes</td>
<td>90%</td>
</tr>
<tr>
<td>Four lanes or more</td>
<td>75%</td>
</tr>
</tbody>
</table>

W = Combined weight on the first two axles which is the same as for the corresponding H truck.

V = Variable spacing – 14 feet to 30 feet inclusive. Spacing to be used is that which produces maximum stress.

Fig (4): AASHTO TRUCK LOADING HS 20-44

Fig (5): Lane Loading HS 20-4
3. RESEARCH STUDY

This research is concerned with studying the analysis of T-beam Bridge by AASHTO specifications. The T-beam Bridge is composed of deck slab 20cm thick and drop beams 50 x 90cm with 200m spacing. The bridge length is 17m. Supported by two elastomeric bearing pads. One end of the bridge is hinged and the other end is sliding in the longitudinal direction. Fig (6) shows plan of the bridge, Fig (7) shows longitudinal section of the bridge and Fig (8) shows transverse section of the bridge.
4. STRUCTURAL IDEALIZATION

The bridge is analyzed as follows:

4.1 AASHTO specifications:

The bridge is first analyzed by using AASHTO specifications. The beam is considered as one dimensional structural elements subjected to the dead loads and live loads. The dead loads included the self weight of the concrete structure and 15cm of asphalt layers to account for future layers. The live load is truck loading HS20-44 multiplied by 1.5 to account for unexpected traffic loadings.

Distribution factor (D.F.) = 1.093

Rear wheel loading = 1.5 × P × D.F × impact

Where P is the AASHTO wheel

\[ I = \frac{15.24}{17 + 38} = 0.28 \]

Rear wheel loading = 1.5 × 7.273 × 1.28 × 1.093 = 15.22 tons

Front wheel loading = \( \frac{15}{4} \cdot 22 \) tons

Fig (9) shows the locations of truck loadings to produce Maximum bending moments and Fig (10) shows the location of truck loadings to produce Maximum shearing force.

Fig (9): Locations of Truck Loading To Produce Maximum Bending Moments
Max. Bending Moment at point O due to live load is 431.5 t.m.
Max. Bending Moment due to Dead load is 98.44 t.m.
Total bending moment according to AASHTO Combination
= 1.3 (Dead load + 2.2 × Live Load)
= 1.3 (98.44 + 2.2 × 106.13)
= 431.5 t.m.

Shear at A = 1.3 (Dead Load + 2.2 × Live Load)
= 1.3 (23.1625 + 2.2 × 28.51)
= 111.65 ton

4.2 Finite Element Method

Finite element mesh for the bridge is carried out as shown in figures (11, 12). The deck slab is composed of finite element plate element and the beams are modeled as beam elements. The loadings locations for maximum shear and bending moments are at the same location as one dimensional model.

The applied loadings at the model is the same loadings used for one dimensional analysis expect they are not multiplied by the distribution factor 50 the rear wheel loading is 13.95 ton and the front wheel loading is 3.5 ton.

The maximum bending moment is shown in Fig (13), and maximum shear shown in Fig (14). The maximum bending moment is 411.8 t.m. While the maximum shearing force is 74.6 ton.

It can be shown that the maximum bending moments and shearing force obtained form the finite element model are smaller than the maximum bending moments and shearing force obtained from one dimensional model (AASHTO specification). This is due to the fact that in three-dimensional structural model, the whole structure working as one unit and the distributions of the loads to the whole structure is much better than one dimensional and all structural elements participating together in carrying the loads.

5. CONCLUSIONS

It can be concluded that designing the T-beam by AASHTO specifications based on one dimensional analysis is adequate when comparing with the output results of three-dimensional finite element method.
REFERENCES