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A COMPARATIVE STUDY OF THE STRUCTURAL ANALYSIS BETWEEN THE INTEGRAL AND THE SIMPLY SUPPORTED BRIDGE

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ABSTRACT

Most bridges in Malaysia have been constructed by using simply supported spans incorporating joints and bearings. As a result, deck expansion joints over every pier and abutment are common features. These expansion joints become the main components that need regular maintenance and replacement. Consequently, the cost to build and maintain such a bridge is expensive in the long run. It is therefore apparent that in future, single and multiple span bridges in this country will be required to be designed as integral bridges with full continuity. This will invariably minimize the maintenance problems and cost, and optimize the use of funds for bridge construction. In relation to that, structural analysis is crucial in designing those bridges. This paper focuses on the structural analysis comparison between integral and simply supported bridges. It was found that the bending moment and displacement of girder in simply supported bridge is always greater than in an integral bridge at the critical point (mid-span). In contrast, the shear force developed in an integral bridge is greater than in a simply supported bridge. The differences in the structural analysis result will produce different specifications of design and detailing in those bridges of similar length bridge span which will then influence the cost of construction.

Keywords: integral; simply supported bridge; structural analysis; bending moment; girder; shear force.

1. INTRODUCTION

There are many bridges that have been constructed worldwide. As it is known, bridges were built to connect between two places or points that are separated by a river, valley or other obstacles such of traffic flow. There are many approaches or methods that have been adopted in order to analyze, design, and construct the bridges. Since the expansion of the United Kingdom's highway network in the 1960's, many bridges have been constructed using simply supported spans incorporating joints and bearings. In Malaysia, many multi-span bridges were constructed as a series of simply supported precast presstresed beams with an in-situ reinforced concrete deck slab. As a result, deck expansion joints over every pier and abutment have become common features. These expansion joints have become the main components that need regular maintenance and replacement (Rajagopalan, 2006). Many problems have

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been encountered in simply supported bridges such as failure of expansion joints due to breakage and removal of transition strips that pose a hazard to traffic, and failure of expansion joints due to exposure of holding-down bolts. Consequently, it will cause water leakage through them, resulting in debris trapped at the bearing shelf. The problems with the simply supported bridges are worsening by ‘walking’ and ‘fallen’ of elastomeric bearings. It is therefore apparent that in future, single and multiple spans bridges in this country will be required to be designed as integral bridges with full continuity. This will invariably minimize the maintenance problems and cost, thus optimizing the use of funds for bridge construction. Integral bridges have proven themselves to be less expensive to construct, easier to maintain, and more economical to own over their life span (NYSDOT Bridge Manual, 2005). The net cost reduction is about 25.14 percent when an integral bridge is used as compared to a simply supported bridge (C. E. Testing Company Pvt. Ltd, 2011). A bridge deck normally consists of a combination of various elements like longitudinal girders, transverse girder, and deck slab. Bridge decks could be formed with monolithic construction or by composite construction of different individual elements or by segmental construction by assembling a number of individual segments with prestressing (Rajagopalan, 2006). The joint between individual elements may be capable of transferring moments, torsion and shear or moment shear, or shear only. The deck therefore, has to be analyzed and designed depending on the possible transfer forces between different elements. The analysis is done after making a mathematical model of the bridge deck depending on the force transfer and force flow. In reality, the bridge decks consist of a number of elements or single elements like slab unless the span to width ratio is large. Lightfoot and Sawko (1960) have pioneered the use of computers for using grillage model. The bending and torsional stiffness in every region of the slab is assumed to be concentrated in the nearest grillage beam. The bending moments which cause flexure in the longitudinal vertical plane is referred to as longitudinal moments and this longitudinal direction mainly corresponds to the direction of traffic flow (Baidar & Leslie, 2003). These moments are designated for providing materials in the longitudinal direction. The longitudinal and transverse shear are caused by the variations in the bending moment in the relevant direction and materials have been provided to see that the stresses caused by them along with longitudinal stress lead to principle stresses which are within the limits of acceptability. Structural analysis is vital to determine the required size and capacity of the component in a bridge such as the girder, pier, abutment and bearing. Basically, structures can be classified as either determinate or indeterminate. A simply supported bridge is treated as a determinate structure while an integral bridge is treated as an indeterminate structure. Statically determinate structures may also be called ‘isostatic’, while determinate single span beams may be called ‘simply supported’ or ‘simple beams’. Structures are classed as indeterminate when their support reactions cannot be calculated by considering only the two equations of equilibrium. For instance, the two span beams shown in Figure 1(b) have three support reactions, and this requires three equations to solve for the value of the reactions. The third equation may be generated by a variety of means that are the scope of specialist books on structural analysis (Hambly, 1991). Indeterminate structures are also called ‘hyperstatic’ or ‘redundant’, while monolithic beams with more than one span are called ‘continuous beams’. In statically determinate structures, the reactions are known absolutely; if one of the supports of the beam shown in Figure 1 (a) was to settle, the support reactions would not be affected, and in consequence the bending moments and shear forces in the beam would also not be changed. In indeterminate structures, the support reactions and the bending moments and shear forces in the beam depend on the rigidity of the supports. For instance, if the central

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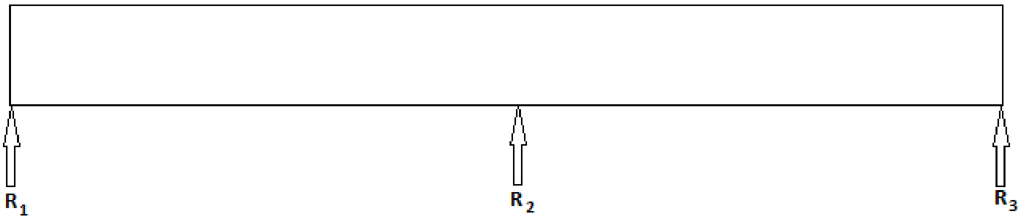
support of the two-span beam shown in Figure 1 (b) was to settle, some of its load would be shed onto the end supports, and additional bending moments and shear forces would be set up in the beam (Benaim, 2008).

(a) Statically determinate beam.



(b) Statically indeterminate beam.

Figure 1: Statically determinate and indeterminate beams.

2. METHODOLOGY

The methodology of study is shown in Figure 2. Basically, the finite element approach has been used to analyse the bridge model. The global analysis of the deck was carried out using a grillage model with seven longitudinal members at 2 m centres representing the precast beams and associated sections of deck slab, and transverse members at 1.85 m centres. The restraint provided by the pier and abutments were represented by rotational springs. The analysis also had to take into account the construction sequence and the resulting distribution of load. As the bridge does not become continuous until the deck slab and diaphragms are cast and the concrete set, all dead load for the main part of the bridge is carried by the precast beams alone (Cusens & Pama, 1975). Therefore, the load effects of the dead weight were analyzed using a simple line beam model, pinned at the abutments and pier, and the results added to those of the grillage model. However, this approach was only considered for the serviceability limit state (SLS) – at the ultimate limit state (ULS) the strain discontinuity between the precast and in-situ concrete is not worth considering and all results are obtained from the grillage model.

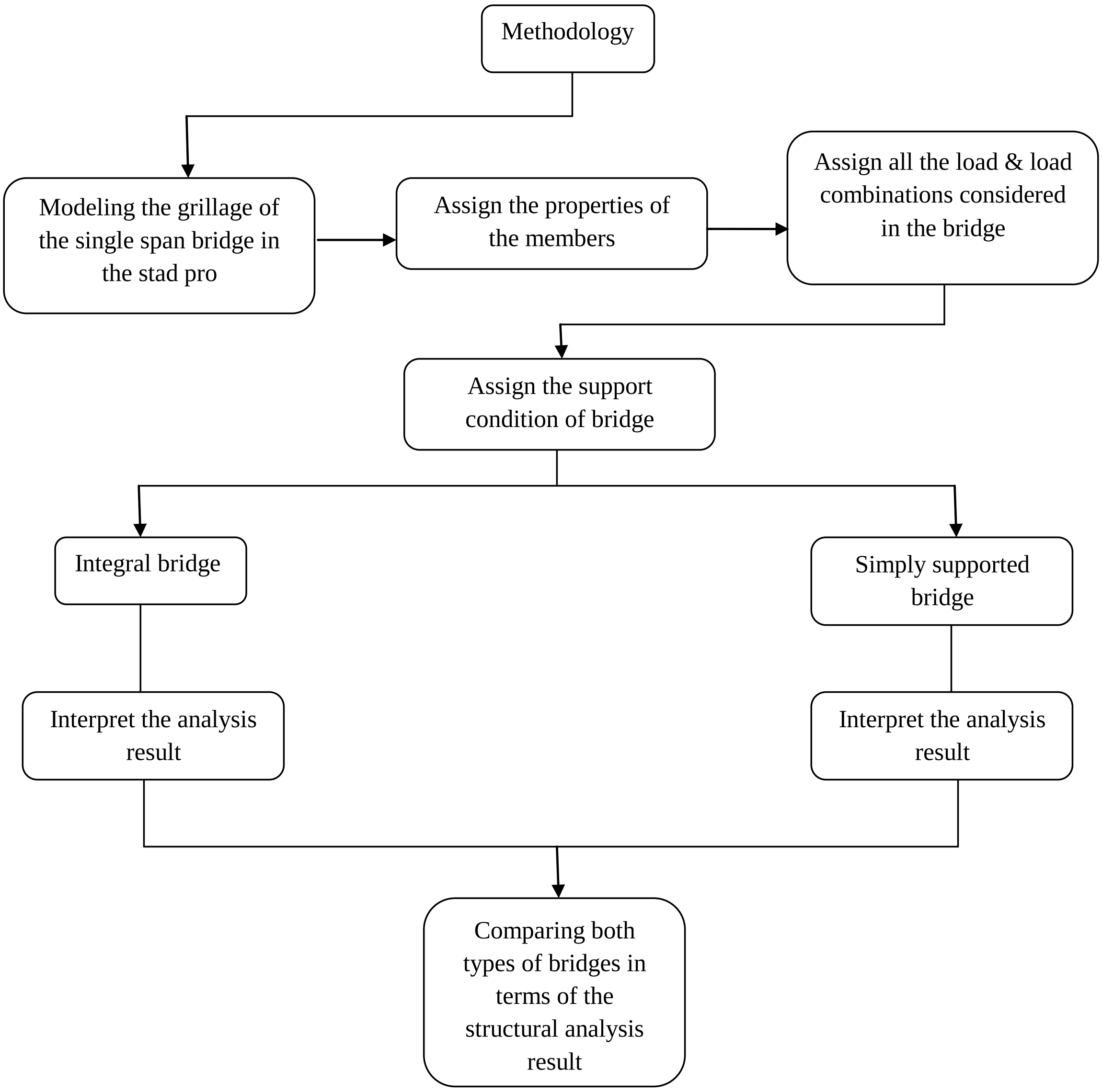


Figure 2: Flow chart of the methodology of study.

2.1 Bridge Modelling

A single span bridge has been adopted to be used in the study. Figure 3 shows the configuration of the bridge cross section while the detailed specification of that particular bridge can be seen in Table 1.

According to the flow chart in Figure 2, analyses of both bridges due to different support condition have been performed using the Staad Pro software. The grillage of the bridge is modelled in Stad Pro according to the calculated ratio of meshing as shown in Figure 4.

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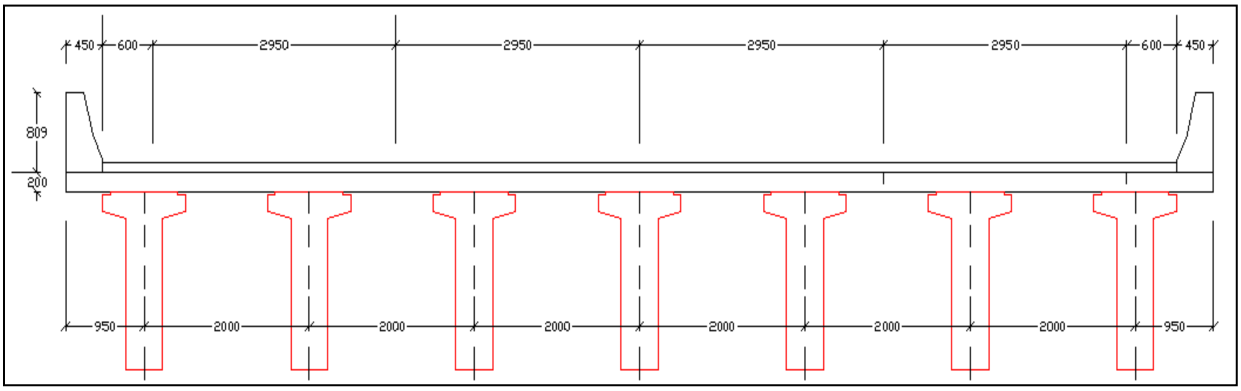


Figure 3: Bridge cross section.

Table 1: Specification of bridge.

Specification	**Dimension**
Span length of bridge	25 m
Width of bridge	13.9 m
Number of national lanes	4 @ 2950 mm / national lane
Spacing of beams	2000 mm
Thickness of slab	200 mm
Number of beams	7

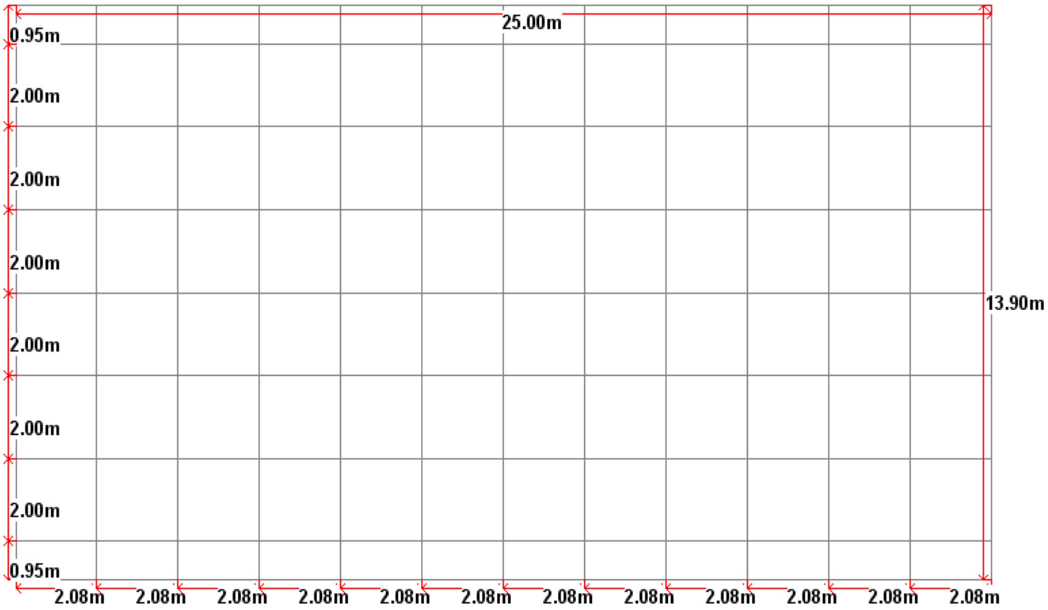
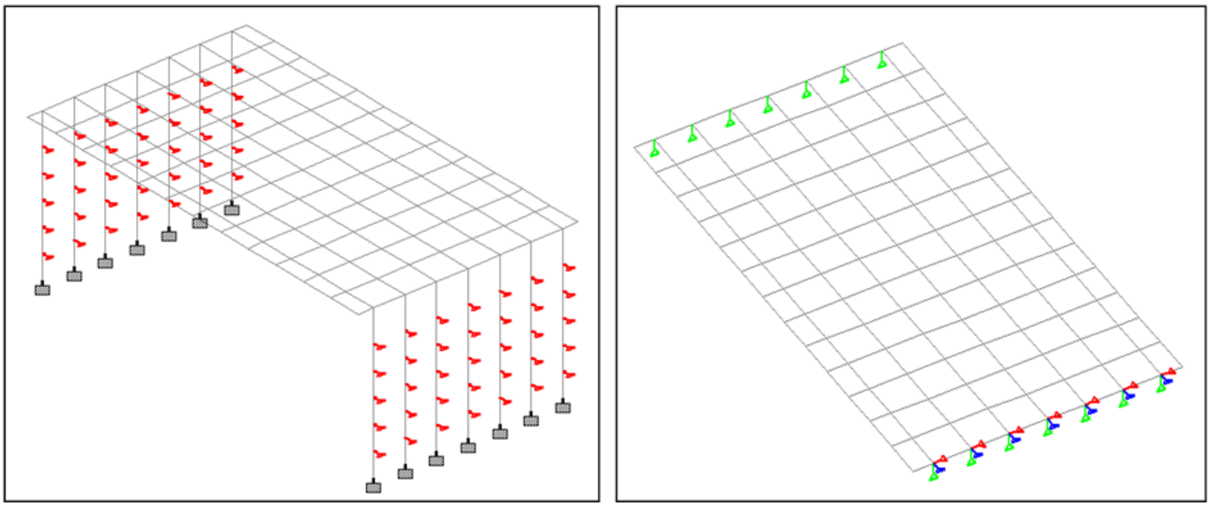


Figure 4: Grillage model of the single span bridge.

This is followed by assigning the members properties of the bridge. All the loads and load combinations are considered in the model according to the code of Loads for Highway Bridges (Clarke, 2001). Then, the support condition of both integral and simply supported are assigned at the end span of the bridge as shown in Figure 5(a) and (b).



(a)Integral bridge (b) simply supported bridge

Figure 5: Support condition of the bridge.

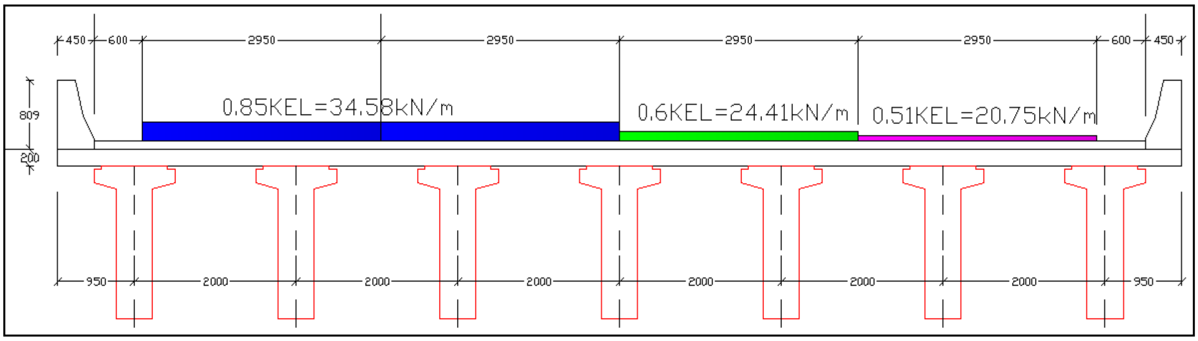
Each condition will be analyzed and interpreted by observing the moment, shear force, and displacement pattern which have been developed due to the variations in the applied load combinations. Finally, both the bridge conditions will be compared due to the different patterns of moment, shear force and displacement that have been developed in each of the model.

2.2 Bridge Loading

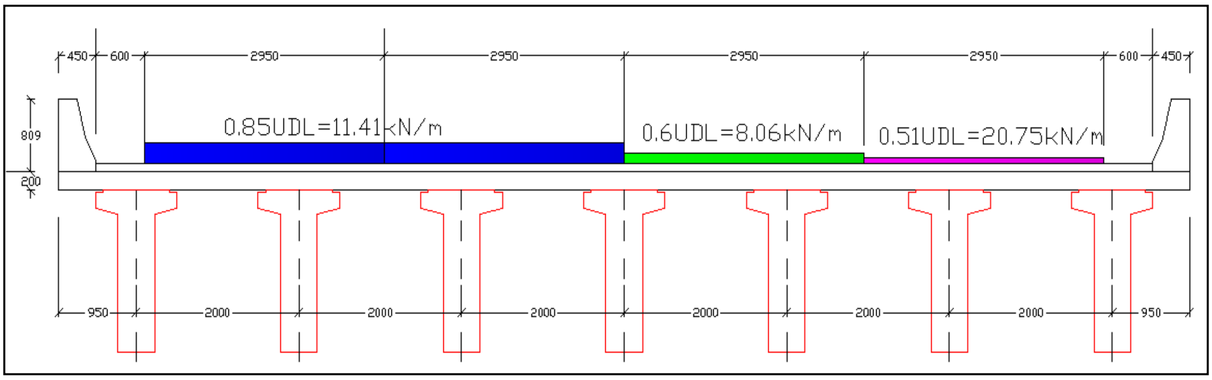
The loads on a bridge deck are made up of: Self weight; the weight of the bare concrete structure. Superimposed dead loads; the weight of permanent loads applied to the bare concrete structure, such as parapets, footpaths, road surfacing etc. These loads do not contribute to the strength of the deck. Live loads; transient vehicular, rail or pedestrian loads applied to the deck. Live loads may be uniformly distributed along the deck (referred to in the text as UDL), corresponding to a busy traffic lane or to a long train, or concentrated, corresponding to a single heavy axle, lorry or locomotive. Environmental loads; principally wind and earthquake. Permanents loads consist of dead loads, superimposed dead loads; loads due to filling materials, differential settlement and load derived from nature of the structural material. The nominal dead load will generally be calculated from the normal assumed values for the specific weight of material. There are in-situ concrete: 24 kN/m^3, precast concrete: 25 kN/m^3, premix: 22.6 kN/m^3 and backfill: 18.9 kN/m^3. Dead loads in the superstructure considered in the analysis are girder, deck slab and diaphragm. The partial safety factor for superimposed dead load appears to be rather large. The reason for this is to allow for the fact that bridge decks are often resurfaced, with the result that the actual superimposed dead loads can be much greater than that assumed at the design stage. Superimposed dead loads on a bridge are premix, parapet and services (Water mains, lamp posts, etc).

2.3 Load Combination

The design code consists of 5 load combinations. However, only Load Combination 1 and Load Combination 3 were considered in the study since the analysis was performed to emphasize the superstructure part. Load Combination 1 comprised permanent loads and appropriate primary live load. The calculated primary live load on the bridge cross section can be seen in Figure 6.



(a) H_A –KEL loads



(b) H_A-UDL loads

Figure 6: Permanent Load + H_A-Uniform Distributed Load (UDL) & Knife Edge Load (KEL).

The H_B loading must be taken into account in the bridge loading. This particular loading is heavy vehicles that cross over the bridge such as lorries and battle tanks. The type H_B30 is defined based on the number of axles and axle distance which differ by countries. Based on the bridge design standard and code of practice (Loads for highway bridges- BD 37/88, 2002), for all public highway bridges, the number of units of type H_B loading that shall be considered is 30 when acting together with H_A and 45 when H_B alone. Figure 7 shows the arrangement of the H_B30 loading combined with other loading.

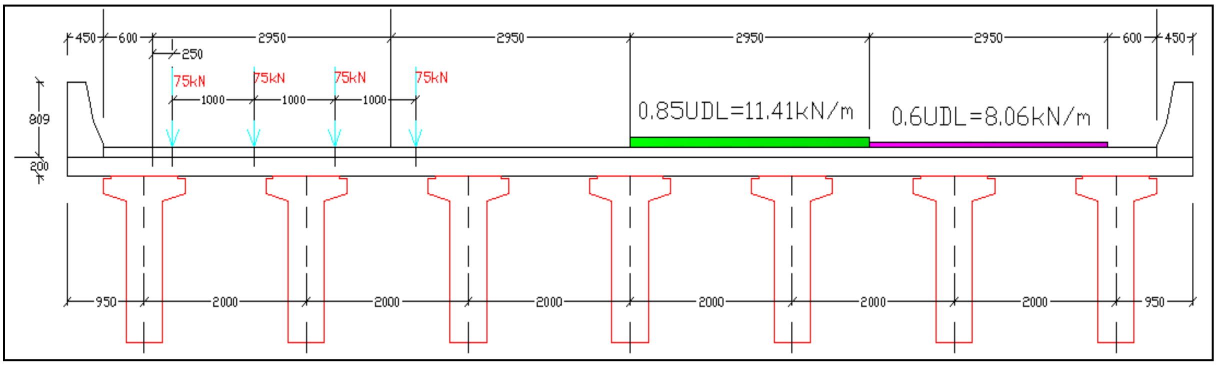
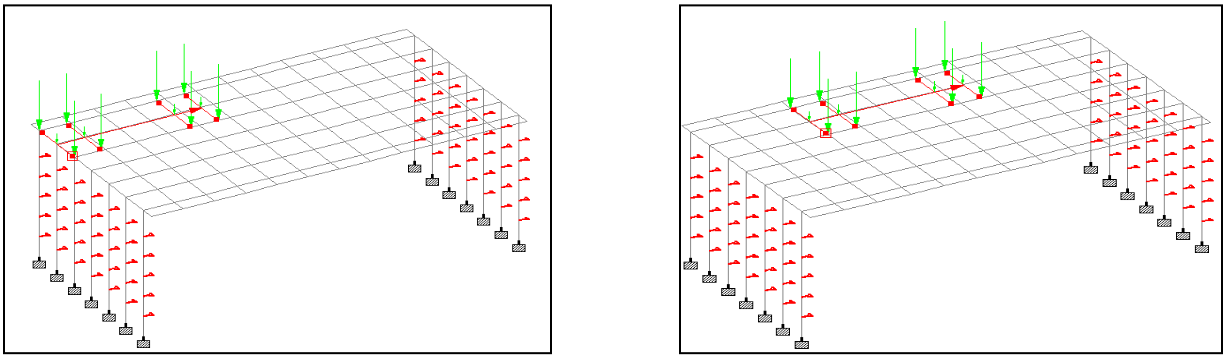


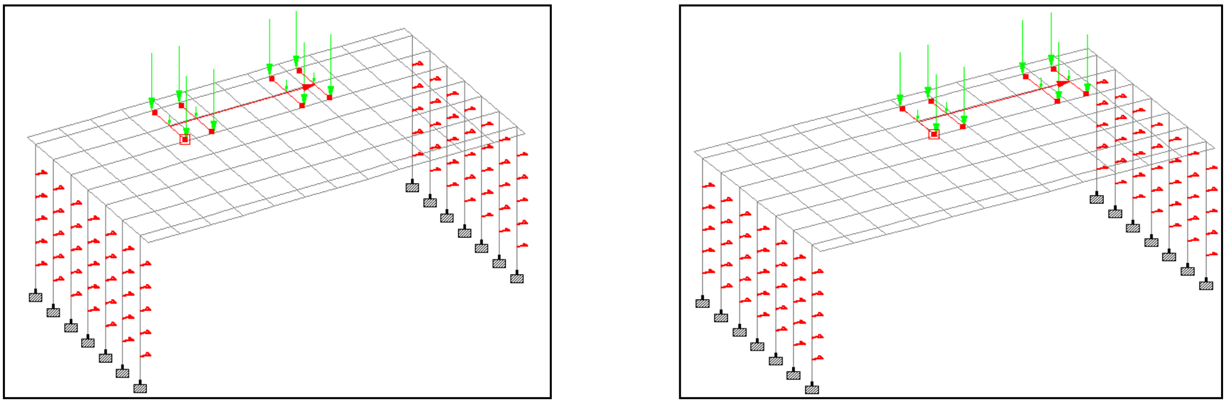
Figure 7: Permanent Load + H_A-UDL & KEL+H_B 30 occupied in 1st and 2nd lane.

According to Figure 7, H_B 30 loads have been occupied in the 1st and 2nd notional lanes while H_A-UDL has been occupied in the 3rd and 4th notional lanes. H_B 30 loads have been applied at four different positions along the bridge span as shown in Figure 8.



(a) H_B applied at edge of bridge

(b) H_B applied at ¼ of the bridge span



(c) H_B applied symmetrically in the bridge span

(d) H_B applied at Mid-span of bridge span

Figure 8: Location of H_B load in the bridge.

Then, the H_B loads have been shifted into the 2nd and 3rd lanes where the vehicle position is located exactly at the centre of the bridge as shown in Figure 9. H_B loads have also been shifted at different positions along the bridge span as shown in Figure 8. H_A-UDL loads have been applied as depicted in Figure 9 under this particular H_B loads condition.

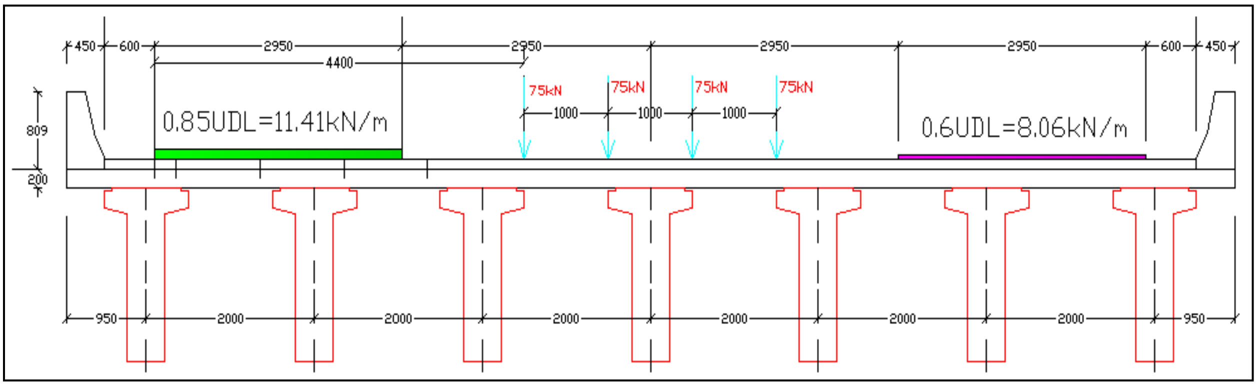


Figure 9: Permanent Load + H_A-UDL & KEL+H_B 30 occupied in the 1st and 2nd lane.

Load Combination 3 is applied by considering permanent loads, appropriate primary live load, loads arising from restraint due to the effects of temperature range and temporary erection loads where erection is being considered. The different primary loads conditions are applied with the permanent loads as explained previously in Load combination 1. Pressure on Abutment was considered in the analysis of the integral bridge as shown in Figure 10. The stiffness of spring values has been assigned at certain depth of the piling.

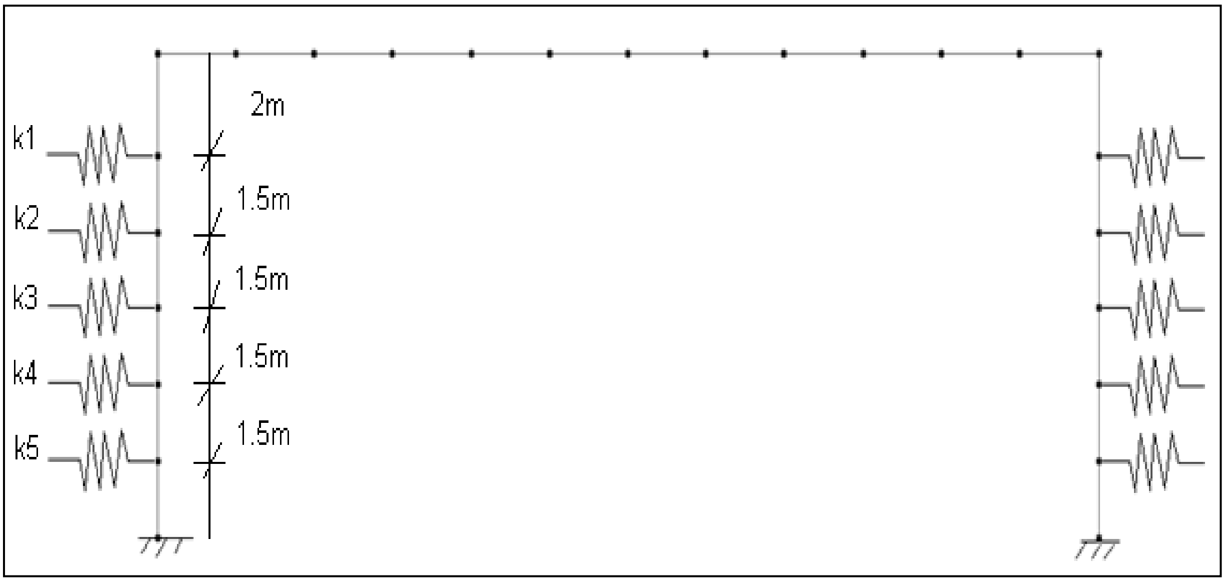


Figure 10: Rotational stiffness in bridge abutment.

3. RESULTS AND ANALYSIS

There are two types of bridges that have been analyzed. Both the simply supported bridge and the integral bridge have been analyzed with identical condition of loads. The support condition is the only parameter that distinguishes both of them. The critical bending moments in all beams were investigated due to varying load combination applied in each type of the single span bridge. It was discovered that the critical bending moment, shear force and deflection occurred under Load Combination 1. Basically, the simply supported bridge shows the critical bending moment at the mid-span of the beam (Figure 11(a)) while the integral bridge shows the opposite pattern of bending moment whereby it comprised sagging moment at the span and hogging moment at the support (Figure 11(b)).

(a) simply supported bridge

(b) integral bridge

Figure 11: Bending moment pattern.

It was found that all the maximum bending moment and deflection have occurred in the middle span of the bridge while the maximum shear forces have been recorded at the support for both types of bridges. The detailed location of those parameters can be seen in Figure 12.

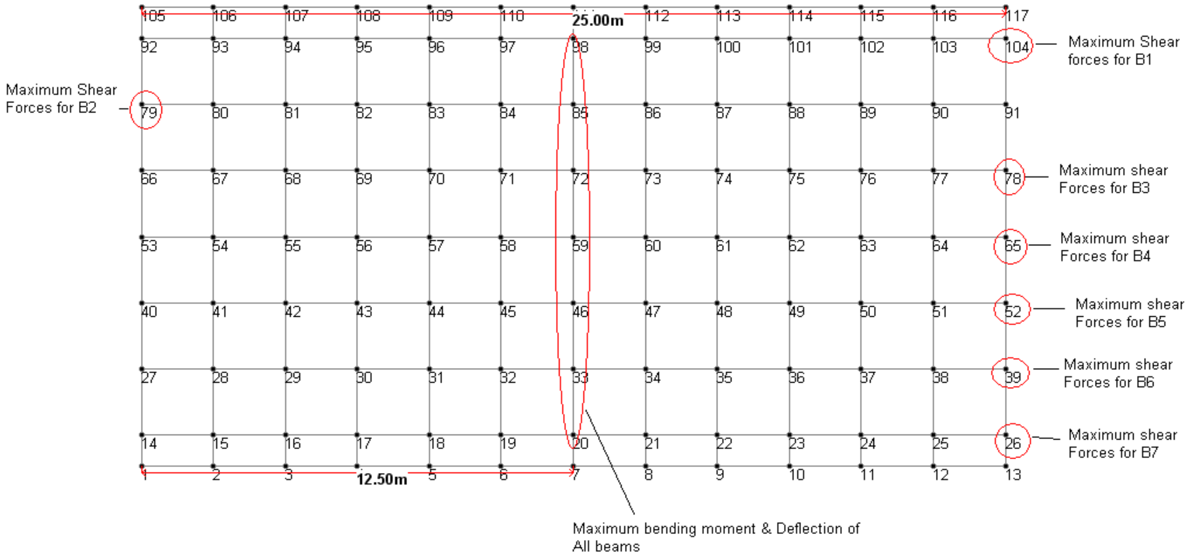


Figure 12: Location of maximum bending moment, shear forces and displacement of both types of bridges under Load Combination 1[Dead Load + H_A-(UDL+KEL)].

Displacement is defined as the movement of a point from its original location. In structural analysis and design, displacement of structure must be rigorously observed to avoid any sequence failure that will lead to the toppling of the structure. The vibration due to vehicle and wind load causes bridge displaced frequently. It is important to make sure that the displacement is within the allowable range. The displacement is observed in this study. By observing Figure 13, it was discovered that the displacement in the simply supported bridge is higher than the integral bridge in all beams. The highest displacement that was recorded occurred at beam 4 which is the central beam at the bridge cross section for both types of bridges. Hence, it can be said that all the loadings are distributed more towards the centre of the beam.

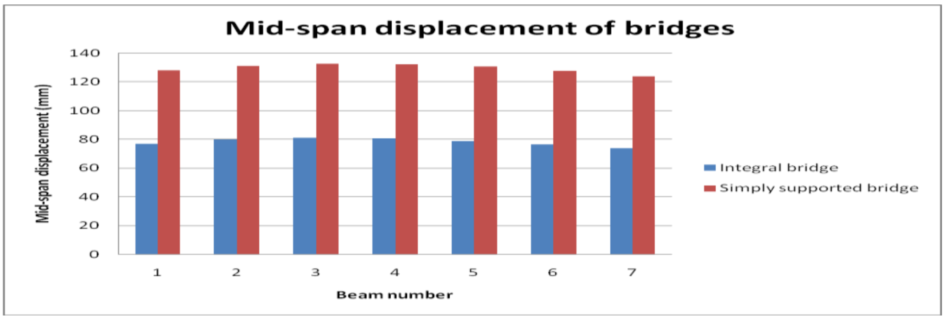


Figure 13: Displacement comparison between the simply supported and integral bridge.

Table 2 shows the detailed values of displacement in both types of bridges. It can be seen that the percentage difference of displacement between both the bridges is around 39 to 40 percent. This indicates significant differences where the simply supported bridge experienced severe displacement compared to the integral bridge.

Table 2: Percentage differences of displacement between both types of bridge.

Beam no	Displacement of integral bridge (mm)	Displacement of simply supported bridge (mm)	Percentage differences (%)
1	77.087	128.186	39.9
2	80.162	131.253	38.9
3	81.218	132.796	38.8
4	80.766	132.495	39.0
5	79.134	130.663	39.4
6	76.722	127.709	39.9
7	73.899	124.126	40.5

This happened due to different support conditions in both types of bridges. The integral bridge is supported by fixed condition where there is full continuity between the girder and the abutment. This will help to reduce the displacement in the integral bridge. Yet, the full continuity can easily cause bridge cracks (due to vibration from vehicle movement) if improper design is produced. In the simply supported bridge, the bearing and joints mechanism can absorb those vibrations to avoid severe cracks from happening.

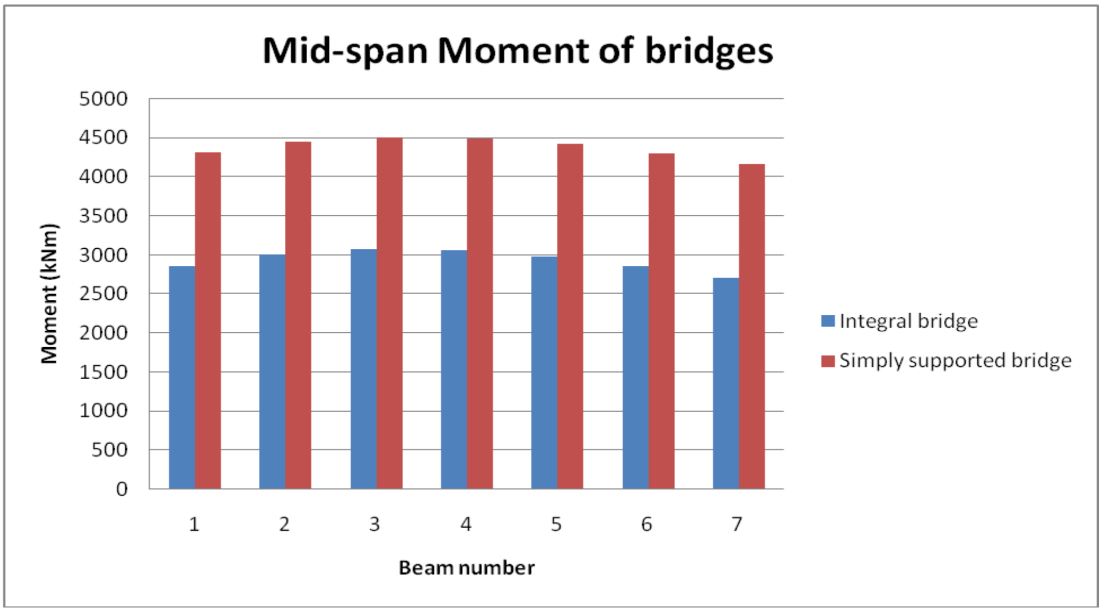


Figure 14: Moment comparison between simply supported and integral bridge.

Bending moment is the value that will be used to determine size of the girder and the number of strands that are going to be used in the bridge design. Basically, the moment value is influenced by the length of the bridge span and the amount of loading imposed. It was discovered that in Figure 14 that the pattern of the bar chart is identical to the one depicted in Figure 13. Therefore, it can be said that the displacement is proportional to moment values. Again, the highest moment that was recorded occurred at beam 4 which is the central beam at the bridge cross section for both types of bridges. The simply supported bridge recorded more bending moment values compared to the integral bridge. Hence, the girder size in the simply supported bridge will be greater than in the integral bridge.

Table 3: Percentage differences of bending moment between both types of bridge.

Beam No.	Bending moment of the integral bridge (kNm)	Bending moment of the simply supported bridge (kNm)	Percentage differences (%)
1	2859.587	4324.197	33.9
2	3006.435	4455.766	32.5
3	3076.640	4516.310	31.9
4	3064.771	4502.071	31.9
5	2989.520	4427.516	32.5
6	2865.652	4311.658	33.5
7	2709.414	4169.217	35.0

The percentage differences in moment values for both bridges is around 32 to 35 percent as shown in Table 3. This is quite similar to the pattern of percentage difference recorded in the diplacement of bridges, which is due to the proportional relationship between the moment and displacement values.

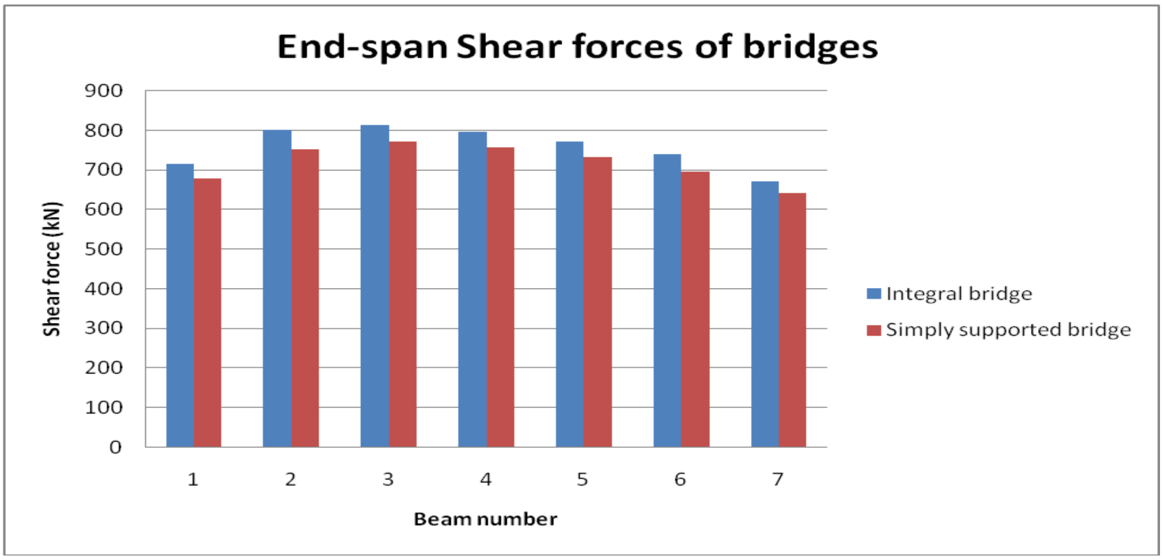


Figure 15: Shear force comparison between the simply supported and the integral bridges.

The maximum shear force location is opposite to bending and displacement. The maximum shear forces for all girders have occurred at the support for both types of bridges. By observing Figure 15, it can be discovered that the shear force in the integral bridge is greater than in the simply supported bridge. This happened due to the difference in the support condition. For full continuity in the integral bridge, the loading will be transferred more to the support as compared to the simply supported bridge. That is why the crack tends to occur at the support in the integral bridge as compared to in the simply supported bridge at the middle span. Huffaker (2013) has reported that the abutment cracking of the 400 South Street Bridge in Salt Lake City, Utah is likely a result of a combination of bridge parameters. These properties include a combination of skew, curvature, span length, and detailing. Integral abutment bridges with more than one of these conditions require additional design checks. Therefore, the proper shear reinforcement detailing is vital in order to resist the shear force developed in the integral bridge. The percentage differences of shear force are around 4 to 6 percent as shown in Table 4.

Table 4: Percentage differences of shear forces in both types of bridges.

Beam No.	Shear force of the integral bridge (kN)	Shear force of the simply supported bridge (kN)	Percentage differences (%)
1	716.251	679.95	5.1
2	801.902	751.658	6.3
3	814.507	773.514	5.0
4	797.94	757.563	5.1
5	771.256	732.15	5.1
6	739.874	695.374	6.0
7	670.776	641.342	4.4

4. CONCLUSION

There are two types of load combination that have been generated in order to analyze both the integral and the simply supported bridges. In summary, the maximum bending moment, shear forces, and displacement have been developed due to Load Combination 1[Dead Load + H_A-

(UDL+KEL)]. It was discovered that the displacement of the girders in the integral bridge is lesser than the displacement of beams in the simply supported bridge. By observing Table 3, it can be seen that the percentage difference of displacement between both types of bridges is around 39 to 40 percent. In beams bending moment, the simply supported bridge is greater than the bending moment in the integral bridge whereby the percentage difference is in the range of 32 to 35 percent. In contrast, the integral bridge has recorded greater shear forces in the beam compared to the simply supported bridge. The percentage difference in shear forces between both types of bridges is small, around 4 to 6 percent. Besides that, it was found that the bending moments had increased due to an increase in the deflection of the beam. Last but not least, it can be concluded that the differences in the structural analysis result in both types of bridges will produce different specifications of design and detailing in those bridges for a bridge span of a similar length.

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