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Adopting Dynamic Transient Response Analysis for Sensors Positioning to Monitor Cable Stayed Bridge

Mohammed Idris Mohammed, Erwin Sulaeman, Faizal Mustapha

Abstract*: Periodically, long span bridges require constant structural assessment and continuous monitoring. Recently, existed bridges and vehicles loading mechanism have influenced many studies to predicate the dynamic bridge response and monitor damage occurrence. The objective of present study is set to monitor the Penang (I) Bridge using finite element model to verify the positioning of sensors. 3D model was developed to evaluate the modal parameter's momentous attitude alteration of the bridge selected grid points and elements. Discussion is focused upon the output parameters such as displacements and stresses generated by vehicles weights. Three types of vehicles were chosen for the purpose of crossing the bridge. In conclusion, from the six lanes of the bridge, high displacements were obtained at the lane 6 (the most left or right side lane) due to vehicles loads at the grid points while maximal stresses were enhanced at lane 6 and 4 (either of the two middle lanes) of the chosen girder beam at bridge spans and cable elements of the infrastructure. Subsequently, sensors were positioned at the grid points in lane 6 and elements located at both lanes due to the mixed loading events.

Keywords: structural health monitoring; cable stayed bridge; dynamic traffic load; weight in motion; finite element method

1. INTRODUCTION

Bridges are key element of the transport system. Their partial or complete closure due to deterioration may cause public traffic flow disruption and significant economic loss which includes the cost of repairing or replacement. Therefore, continues evaluation at regular interval monitoring becomes essential to maintain the safety and durability of the bridge infrastructural components [1]. The evaluation methods of bridges were categorized in the following four strategies: Visual inspection, Structural health monitoring, sensor types, and Static bridges infrastructure monitoring approach

1.1. Visual inspection strategy

At certain period in time, bridges evaluation was carried out based on recurrent visual observation in term of load rating factor (RF) to predict the carrying capacity of bridge structure or condition rating of the bridges physical state. However, the method has proved to be functionally of limited activities for long spans infrastructures due to the inaccessibly of the unexposed elements [2-5]. Nowadays, the visual inspection is applied to inspect the external surfaces of long bridges. Despite that such inspection demands for individual expertise, reliability and quality defect observation with the accuracy of damage positioning. However, research continues to determine another reliable and rapid concept of bridge evaluation. Here, the method of structural health monitoring was introduced.

1.2. Structural health monitoring strategy

Structural health monitoring is significant to be implemented for securing existed bridges of continues operation safely in long term performance. The infrastructures exhibit material aging, vehicles over loading, distresses and the environmental influences which lead to symptoms of deterioration and deficiency in bridge load capacity [6-10]. The SHM concept stands for automated remote sensing tool and remote monitoring for the sequence of gradual changes in parameters of structure behavior as a consequence of external reactions. These parameters have resulted alteration in the shape, dimension, and position. The objective is to obtain quanti-tative information so that bridge qualitative assessments is improved. The application is evaluating the load distribution, stress level and serviceability such as deflection and stress. [11-15]. While [16] describes structural health monitoring is concept of finding the physical and parametric model of bridge structure identity utilizing the time-dependent data. The signals utilized in SHM is not only from vibrations but also from slowly changes quasi-static effects.

1.3. Sensors types utilized at the structural health mon-itoring

Bridge health monitoring requires the implementation of system involves instruments that provide information and analysis of the parameters. The instruments function is to assess the operational performance reliability and damage detection of Cable Bridge through the data collected from the sensors or transducers. Cur-rently bridges are monitored as result of vehicles, temperature, wind and seismic loading. Also, monitoring including the bridges responses such as displacement, deformation, strain or stress of bridge components. In this prospect sensors are selected and posi-tioned accordingly [17]. Sensors which are commonly used for cable stayed bridges are accelerometers on the deck, pylons, stay cables, Strain gauges and load cells on the stay cables, Displacement sensors on the expansion joints, and Temperature sensors in the deck to detect freezing conditions

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Mohammed Idris Mohammed, Assistant Manager for Training and Development, Efficomm Global Resources Sdn Bhd Kuala Lumpur, Malaysia (email: esulaeman@iium.edu.my)
Erwin Sulaeman, Department of Mechanical Engineering, International Islamic University Malaysia53100 Kuala Lumpur, Malaysia
Faizal Mustapha, Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia , 43400 Serdang, Malaysia

and Linear variable differential transducer (LVDT) sensors on the stay cables to measure movement.

1.4. Static bridges infrastructure monitoring approach

Traditionally, loaded trucks are positioned along bridge's deck to assess its safety and evaluate the responses for example strain (displacement). The bridge responses are compared with finite element model of the bridge by numerical simulation method. Also, the bridge model would could be updated for future prediction [18-20]. However, the application of load testing equipment for bridge monitoring could be disadvantage due to the high cost, limited durability and unpractical application [21]. Meanwhile, static loading analysis application was successfully carried out adopting finite element model-based approach to assess a cable stayed bridge behaviour and condition as result of British Standard load [22].

1.5. Dynamic bridges infrastructure monitoring ap-proach

Existing major bridges which are monitored dynamic as a conse-quence of the sudden excitation of dynamic loads to bridge structure. Such excitation leading to vibration characteristics (acceleration). The bridge responses are measured in term of natural frequencies and the vibration mode shapes. These two factors would determine the deterioration at the bridge infrastructure. Also, numerical simulation method could be employed at finite element model of the bridge to evaluate the changes in the dynamic features [23-28]. Usually, the bridge response to dynamic loads is higher than that of static loading. Natural Frequencies and Vibration mode shapes of cable stayed Bridge responses were prosperously determine at dead load state [29]. At this point, the present investigation utilized dynamic analysis of three types of pre-selected self-loaded vehicles such as truck, bus and van. The vehicles were crossing at two lanes with speed of 80m/s. The selected lanes were high speed lane-6 and low speed lane-4 of the bridge deck. The current study has chosen previous grid points and elements of high displacement and stresses [30]. The selected grid points and elements at the spans, deck-tower in addition to the cable elements were investigated their displacements and stresses at two lanes for example the inner and outer of the bridge deck. Meanwhile, transverse deflection evaluates the lateral redistribution of loads whereas the longitudinal deflection assesses the grids behavior. Finite element method and algorithm were carried out to examine the dynamic bridge reactions. The objective of the analysis effort is to investigate the most probable reactions of the cable stayed bridge when a range of vehicles loads were applied so that sensors are positioned at the high displacement and stress locations. The investigation may convert useful information to evaluate the performance of the cable stayed bridge and may help to achieve efficient design aspect / configuration.

2. METHOD

2.1. Bridge geometrical description of Penang (i) bridge

Penang (I) bridge is a cable stayed bridge which is singled out globally for its esthetical particular look as shown in Figure 1. The deck has slender thickness of a post-tensioned concrete slab with substantial optional span sizes. The bridge has six lanes. The pre-stressed superstructure has gratifying vibration damping features [31-33].

Fig. 1: The oblique view of Penang (I) Bridge in Malaysia

The 440m long harp type bridge has two pairs of (H) shape towers at height 101.5m. The superstructure has three span segments, two flanking spans at the approach level of 107. 5m then it commoves to be higher level toward the main span of 225m as shown in Figure 2 [34]. The width of the deck is 29.7 m in total, narrows up at the main piers to 24.7m so that can accommodate the inside tower faces. The superstructure comprises of 98 edge girder segments and 147 floor beams with deck slab segments. One edge girder at main span is held up by cable stay of 11 single plus one pair while the other edge on the end span is supported by 12 pairs carrying one-quarter of the bridge.

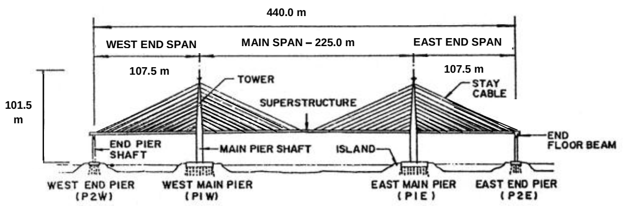

Fig. 2: Plan of Penang Bridge (Ref. Chin, 1988)

2.2. Finite element model of Penang (I) bridge

The Malaysian highway authority had provided a 2D model of the bridge [34]. The model is then improved to 3D with the aid of Nastran Patran program. At the meantime, convergence method was applied to the finite element model to identify the errors and discrepancy. Subsequently, the global coordinate was set at the left end of the model as shown in Figure 3. Meanwhile, the tower's footages and pier's ends were considered as fixed boundary conditions [35]. Moreover, the finite element bridge model members consist of 2514 gird points, 1287 CBAR elements, 144 CROD elements, 1528 CQUAD4 elements and 4 RBAR1 elements (36). Furthermore, the model analysis had adopted small displacement where Benouli-Euler beam and Mindlin plate theories were employed at the deck-towers members. In the same way, the cable members were modeled as a rod since only axial forces were considered.

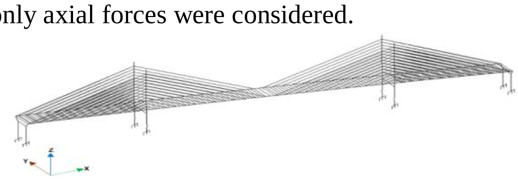

Fig. 3: Developed 3D finite element bridge model

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2.3. Methodology

The input file had comprised the geometrical data of the bridge and weight of the infrastructure. The file also included computed data of the codes such as DAREA, TLOAD and DELAY. Then preprocessing stage was carried out using Nastran program to obtain the displacement, forces and stresses at the grid points and elements of bridge members. Next, the results obtained were pro-cessed statistically with the Vehicles weight axles and wheel time step on / step off along the bridge length for lane-6 and lane-4. Besides, the article has focused on the displacements and stresses of selected grid points and elements to determine their influence at the bridge outer lane-6 and the inner lane-4. Comparison between the two results were encountered and plotted. The highest dis-placements of the grid points and maximum stressed elements reflected the sensors locations at the bridge members at lane-6 or lane-4.

3. RESULT AND DISCUSSION

The structure of interest is continuously exposed to traffic load which causes significant changes in its mechanical properties and susceptible to random vibrations in its long service period leading to degrading by ageing [37]. The structural changes were investigated using dynamic characteristic with the application of weight in motion (WIN) method. Mixture of three vehicles were selected for the purpose. The bridge owners limited vehicles to cross at speed of 80 m/s. In this case, two lanes e.g. low speed lane-4 and high speed lane-6 were proposed [38]. The methodology of weight in motion is successful approach. Its sensing system is developed to preserve the bridge structure and evaluate the effects of carrier loading behavior including the type of transporter [39-40]. The evolved statistical method produces displacement, forces and stresses at the infrastructure. In this study, the parameters of interest were displacement and stresses. Consequently, the high / maximum values at either lane were indication of hot spot grid points and critical elements which prerequisite sensors to be positioned accordingly. Here, grid points and elements were selected at the bridge structure since would be explicitly complicated to assess the entire structure members for critical locations. So, two grid points to determine displacement, two elements at the span-tower and three cables elements at the spans to assess stresses were selected [30]. Starting with the displacements of the grid points such as at the middle of main span. The analysis revealed that high longitudinal displacement when the truck, bus and van crossing lane-6 (high speed lane) more than that of the same truck, bus and van travelling lane-4 (low speed lane) as displayed in Table 1. As well as Figure 4 portrays that lane-6 vehicles displacements deflections were at the upper level and shifting the lane-4 vehicles' displacements below. Since bridge supports are carrying the spans at the outer edge close to lane-4. Despite, the longitudinal displacements readings were limited signifying the high-level of structural stiffened. Nevertheless, the sensors positioning would be when truck at maximum displacement of 0.515m at 0.53s, bus max. displacement 0.292m at 0.49s and van max. displacement 0.062m at 0.47s.

Table 1: Max. and Min. longitudinal displacements of three mixed vehicles crossing lane-6 and lane-4 at mid-main span grid point

Vehicle Type	Time (s)	Max. Longitudinal Displacement (m)	Vehicle Type	Time (s)	Min. Longitudinal Displacement (m)
Truck L6 Max.	0.53	0.515	Truck L6 Min.	9.17	0.0001
Truck L4 Max.	0.54	0.384	Truck L4 Min.	9.96	-0.0013
Bus L6 Max.	0.49	0.292	Bus L6 Min.	9.88	-0.0015
Bus L4 Max.	0.49	0.251	Bus L4 Min.	9.89	0.0007
Van L6 Max.	0.45	0.062	Van L6 Min.	9.87	0.0003
Van L4 Max	0.47	0.045	Van L4 Min.	9.88	-0.0001

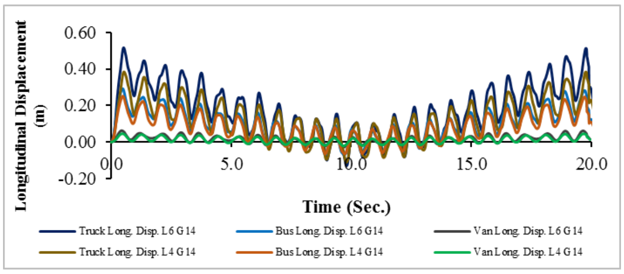

Fig. 4: Longitudinal displacements of mixed vehicles at Lane 6 Vs. Lane 4 for middle main span grid points.

In a similar manner, the rotational displacement of the mixed ve-hicles at lane-6 ascending further than that of lane-4 as presented in Table 2 the maximum – minimum vehicles rotational displacements and illustrated Figure 5. Although, the rotational displacement readings were insignificant due to the structural strength which opposes the twisting. Yet, Sensor positioning would contribute to prevent future deterioration of the bridge with age. The sensors could be placed when maximum rotational displacement of truck crossing at 0.0083° with time of 2.06s, bus max. displacement at 0.0028° of 2.03s and van max. displacement 0.0007° of 17.86s. Furthermore, the max. displacement of the truck and bus arose at early stage of the crossing while the van was at the end of the travelling path.

Table 2: Max. and Min. rotational displacements of three mixed vehicles crossing lane-6 and lane-4 at Mid-Main Span grid point.

Vehicle Type	Time (s)	Max. Rotational Displacement (deg.)	Vehicle Type	Time (s)	Min. Rotational Displacement (deg.)
Truck L6 Max.	2.06	0.0083	Truck L6 Min.	0.06	-0.000008
Truck L4 Max.	2.02	0.0021	Truck L4 Min.	0.06	0.000014
Bus L6 Max.	2.03	0.0028	Bus L6 Min.	0.06	0.000006
Bus L4 Max.	2.03	0.0011	Bus L4 Min.	0.06	0.000024
Van L6 Max.	17.86	-0.0007	Van L6 Min.	0.06	-0.000002
Van L4 Max	17.81	-0.0002	Van L4 Min.	0.06	0.000004

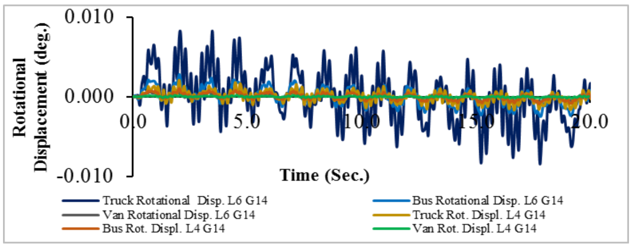

Fig. 5: Rotational displacements of mixed vehicles at Lane 6 Vs. Lane 4 for Mid Main Span grid points.

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Also, similar state of sensor positioning of another grid point at the side span. The longitudinal displacements readings of mixed vehicles at lane-6 versus lane-4 were presented in Table 3 and depicted at Figure 6. The lane-6 readings were slightly high de-formation since the lane is at distance away from cables and towers supports as mentioned previously. Meanwhile, sensor placement would be appropriate at locations were displacements elevated due to the interaction between the weight of vehicles and bridge supports. So, in the case sensor placement would be when truck was displaced 0.106m at 1.25s, bus was distant 0.0574m at 1.25s and van was located 0.0076m at 1.25s.

Table 3: Max. and Min. longitudinal displacements of three mixed vehicles crossing lane-6 and lane-4 at End Side Span grid point

Vehicle Type	Time (s)	Max. Longitudinal Displacement (m) side span grid point	Vehicle Type	Time (s)	Min. Longitudinal Displacement (m) Side span grid point
Truck L6 Max.	1.25	-0.1060	Truck L6 Min.	2.01	0.0003
Truck L4 Max.	1.25	-0.0771	Truck L4 Min.	17.32	-0.0008
Bus L6 Max.	1.25	-0.0574	Bus L6 Min.	3.19	-0.0002
Bus L4 Max.	1.25	-0.0505	Bus L4 Min.	3.19	-0.0002
Van L6 Max.	1.25	-0.0076	Van L6 Min.	3.18	0.0002
Van L4 Max	1.25	-0.0067	Van L4 Min.	3.18	0.0001

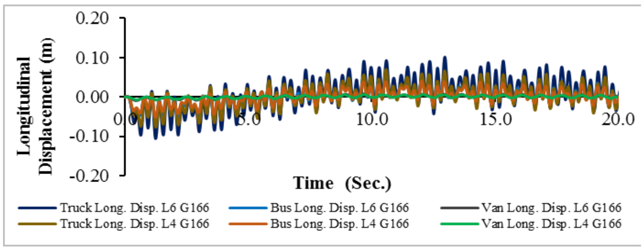

Fig. 6: Longitudinal displacements of mixed vehicles at Lane 6 Vs. Lane 4 for side span grid points.

However, the rotational displacements developed at the selected end side span grid point of lane-6 and lane-4. Table 4 and Figure 7 show the deflections of displacements at grid point lane-6 and lane-4. Subsequently, the lane-6 grid point was at upper level than the other lane. Also, the maximum displacements readings were limited which signifies that the infrastructure capacity would overcome twisting due to the mixed vehicles weights. Then, sensors positioning could be of use for future purpose as the structure wear out with usage. Therefore, the locations of the sensors could be when truck displaced 0.0488° at 19.2s, bus was 0.0183° at 19.16s and van was 0.0049° at 19.05s.

Table 4: Max. and Min. rotational displacements of three mixed vehicles crossing lane-6 and lane-4 at End Side Span grid point.

Vehicle Type	Time (s)	Max. Rotational Displacement (deg.) side span grid point	Vehicle Type	Time (s)	Min. Rotational Displacement (deg.) Side span grid point
Truck L6 Max.	19.20	-0.0488	Truck L6 Min.	0.01	-0.000005
Truck L4 Max.	19.20	-0.0104	Truck L4 Min.	0.01	-0.000001
Bus L6 Max.	19.20	-0.0179	Bus L6 Min.	0.01	-0.000005
Bus L4 Max.	19.20	-0.0064	Bus L4 Min.	0.01	-0.000001
Van L6 Max.	19.20	-0.0044	Van L6 Min.	0.01	-0.0000016
Van L4 Max	19.20	-0.0010	Van L4 Min.	0.01	-0.0000002

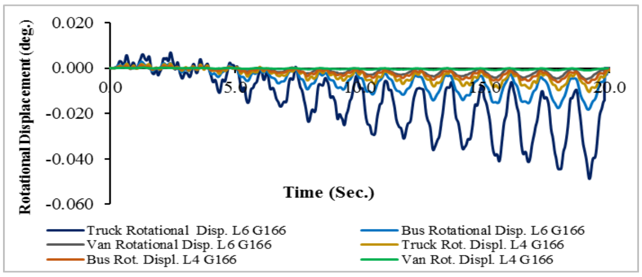

Fig. 7: Rotational displacements of mixed vehicles at Lane 6 Vs. Lane 4 for side span grid points.

At the meantime, analysis included bridge elements at various locations along the infrastructure to verify the stresses lead by the mixed vehicles wheels weights at lane 6 and lane 4. The maximum- minimum stress results of the Span CBAR beam elements 9195 were provided in Table 5 and exhibit in Figure 8. The maximum stress readings exposed that the element located at lane-6 was subjected to pressure more than same element at lane-4. For example, the pressure exerted by the truck on lane-6 element was 1.52×108 N/m2 and lane-4 element 7.64×107 N/m2, bus pressure axle weight on lane-6 element was 6.76×107 N/m2 and lane-4 element 4.58×107 N/m2 while van axle weight recorded pressure lane-6 element was 1.34×107 N/m2 and lane-4 element 7.95×106 N/m2. As mentioned previously, lane-6 was unsupported by cables or towers. Thus, sensors placement would be at the lane-6 element.

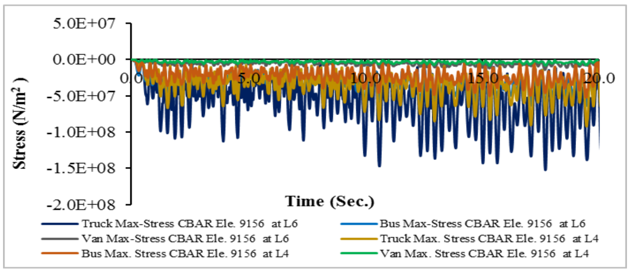

Fig. 8: Max.-Min. Stresses of mixed vehicles at Lane 6 Vs. Lane 4 for element CBAR span beam 9156.

Likewise, CBAR main span beam elements 9190 located at the spans have their stresses readings shown in Table 5 and depicted in Figure 9. The maximum stresses were at lane-6 for being un-supported lane. The truck axles weight pressure influence was 1.18×107 N/m2 at lane-6 compared with 9.78×106 N/m2 at lane-4, for the bus axle weight stressed the element to 5.90×106 N/m2 at lane-6 compering with 5.28×106 N/m2 at lane-4 and van stress on the element was 9.55×105 N/m2 at lane-6 compared with 7.48×105 N/m2 at lane-4. Hence, sensor is required to be implemented at the element located in lane-6.

Table 5: Max. and Min. stress of three mixed vehicles crossing lane-6 and lane-4 at span beam element 9190

Vehicle Type	Time (s)	Max. Stress (N/m^2) Element 9190 Tower-Spans	Vehicle Type	Time (s)	Min. Stress (N/m^2) Element 9190 Tower-Spans
Truck L6 Max.	1.50	-1.18E+07	Truck L6 Min.	0.27	-1.72E+06
Truck L4 Max.	1.50	-9.78E+06	Truck L4 Min.	0.27	-1.24E+06
Bus L6 Max.	1.50	-5.90E+06	Bus L6 Min.	0.27	-2.56E+06
Bus L4 Max.	1.50	-5.28E+06	Bus L4 Min.	0.27	-2.16E+06
Van L6 Max.	1.50	-9.55E+05	Van L6 Min.	0.27	-5.21E+05
Van L4 Max	1.50	-7.48E+05	Van L4 Min.	0.27	-3.76E+05

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Likewise, elements span beam CBAR 9190 located at the spans have their stresses readings shown in Table 5 and depicted in Fig-ure 8. The maximum stresses were at lane-6 for being unsupported lane. The truck axles weight pressure influence was 1.18×107 N/m2 at lane-6 compared with 9.78×106 N/m2 at lane-4, for the bus axle weight stressed the element to 5.90×106 N/m2 at lane-6 compering with 5.28×106 N/m2 at lane-4 and van stress on the element was 9.55×105 N/m2 at lane-6 compared with 7.48×105 N/m2 at lane-4. Hence, sensor is required to be implemented at the element located in lane-6.

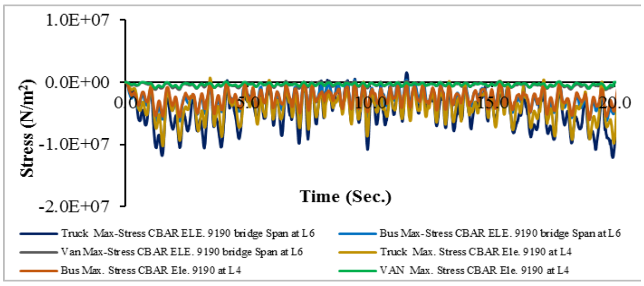

Fig. 9: Max-Stresses of mixed vehicles at Lane 6 Vs. Lane 4 for element span beam 9190.

Moreover, the study proceeded to preform analysis at the Cables elements coded E7 End Side Span, C9 Main Span and E1 short cable of the 3rd tower opposite to the 1st tower which were carrying the spans. The maximal-minimal stresses of the cables E7, C9 and E1 were displayed in Table 6, 7, 8 and portrayed in Figure 10, Figure 11, Figure 12 respectively. In the case of element C7, the Cable is close to the towers support so the stresses readings ob-tained at lane-4 is less than that of lane-6 when the individual mixed vehicles crossing the bridge. Here, the maximal stresses of the truck at lane-6 was 1.69×108 N/m2 in contrast with 7.62×107 N/m2 at lane-4. Similarly, the maximal stresses caused by bus was 4.98×107 N/m2 while the same bus produced less weight pressure of 4.41×107 N/m2 at lane-4. Whereas, the van maximal stresses were 8.38×106 N/m2 at lane-6 and 7.23×106 N/m2 in lane-4 referring to Table 6. Thus, sensor would be placed at lane-6 for the cable element E7.

Table 6: Max. and Min. stress of three mixed vehicles crossing lane-6 and lane-4 at cable element E7 End side Span

Vehicle Type	Time (s)	Max. Stress (N/m²) Cable Element E7 End Side Span	Vehicle Type	Time (s)	Min. Stress (N/m²) Cable Element E7 End Side Span
Truck L6 Max.	16.63	-1.69E+08	Truck L6 Min.	0.32	-1.79E+07
Truck L4 Max.	16.63	-7.62E+07	Truck L4 Min.	0.32	-1.17E+07
Bus L6 Max.	16.63	-4.98E+07	Bus L6 Min.	0.32	-2.58E+07
Bus L4 Max.	16.63	-4.41E+07	Bus L4 Min.	0.32	-2.04E+07
Van L6 Max.	16.63	-8.38E+06	Van L6 Min.	0.32	-5.43E+06
Van L4 Max	16.63	-7.23E+06	Van L4 Min.	0.32	-3.54E+06

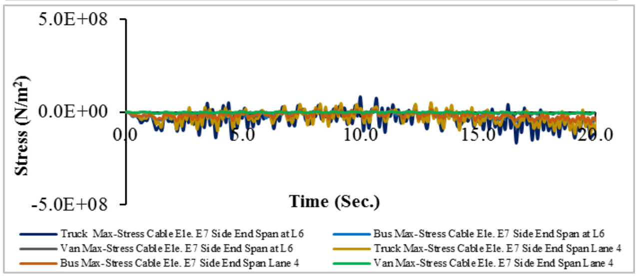

Fig. 10: Max-Stresses of mixed vehicles at Lane 6 Vs. Lane 4 for Cable element E7 End Side Span

In the same way, cable element C9 at the main span investigated to verify the location of sensor. The results revealed that vehicles weight pressures at lane-6 enhanced slightly than of lane-4 as shown in Table 7 and Figure11. For instance, the truck maximal stress 3.15×108 N/m2 at lane-6 compared with 2.16×108 N/m2 at lane-4. Also, maximal stress for bus was 1.43×108 N/m2 lane-6 and 1.18×108 N/m2 lane-4. Finally, the maximal stress in lane-6 was improved to 2.42 N/m2 while in lane-4 was 1.76×107 N/m2. Obviously, sensor would be placed at cable C9 the main span of lane-6.

Table 7: Max. and Min. stress of three mixed vehicles crossing lane-6 and lane-4 at cable element C9 main Span

Vehicle Type	Time (s)	Max. Stress (N/m²) Cable Element C9 Main Span	Vehicle Type	Time (s)	Min. Stress (N/m²) Cable Element C9 Main Span
Truck L6 Max.	1.41	-3.15E+08	Truck L6 Min.	14.60	2.82E+07
Truck L4 Max.	1.41	-2.16E+08	Truck L4 Min.	14.60	3.30E+07
Bus L6 Max.	1.41	-1.43E+08	Bus L6 Min.	14.60	-4.39E+06
Bus L4 Max.	1.41	-1.18E+08	Bus L4 Min.	14.60	-2.71E+06
Van L6 Max.	1.41	-2.42E+07	Van L6 Min.	14.60	-3.00E+05
Van L4 Max	1.41	-1.76E+07	Van L4 Min.	14.60	3.28E+05

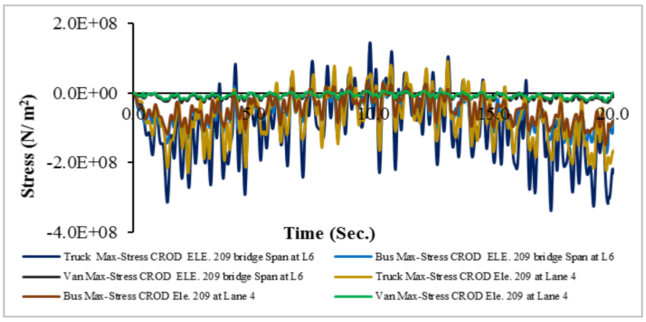

Fig. 11: Max-Stresses of mixed vehicles at Lane 6 Vs. Lane 4 for Cable Element C9 at main span.

The last cable of the bridge span was cable element E1 at the 3rd tower. Maximal-Minimal stress reading were portrayed in Table 8 and Figure 12. The readings exposed that mixed vehicles weights generated stresses at lane-4 better level than that of lane-6 which indicate the cable is critical at lane-4 despite the supports. Hence, sensor would be positioned at this cable when it is on lane-4. The investigation disclosed that not all selected elements of the bridge members would be influenced by the mixed individual vehicles weights at the same lane.

Table 8: Max. and Min. stress of three mixed vehicles crossing lane-6 and lane-4 at cable element E1 at 3rd tower

Vehicle Type	Time (s)	Max. Stress (N/m²) Cable Element 2124 Bridge Span	Vehicle Type	Time (s)	Min. Stress (N/m²) Cable Element 2124 Bridge Span
Truck L6 Max.	18.93	-1.57E+07	Truck L6 Min.	0.28	3.73E+05
Truck L4 Max.	18.93	-2.13E+07	Truck L4 Min.	0.28	-1.41E+06
Bus L6 Max.	18.93	-9.52E+06	Bus L6 Min.	0.28	-6.47E+05
Bus L4 Max.	18.93	-1.28E+07	Bus L4 Min.	0.28	-2.47E+06
Van L6 Max.	18.93	-1.39E+06	Van L6 Min.	0.28	1.13E+05
Van L4 Max	18.93	-1.83E+06	Van L4 Min.	0.28	-4.28E+05

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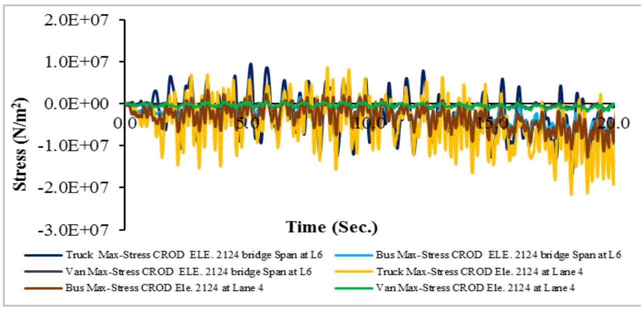

Fig. 12: Max-Stresses of mixed vehicles at Lane 6 Vs. Lane 4 for short Cable element E1 at the 3rd tower.

Sensors positioning to monitor bridge health could be adopted when high speeds of mixed vehicles crossing the bridge lanes. A statistical method with the aid of Finite Element Analysis at first would contribute to determining the bridge deterioration.

4. CONCLUSION

The contribution of the article was to determine the utmost dis-placements of selected bridge grid points at tower-spans sections and maximal stresses at elements located on span-tower members include cables elements at end side and main spans caused by three individual mixed weight in motion vehicles loading in lane 6 and 4 of the infrastructure. The results revealed that the chosen grid points and elements at lane 6 were influenced by the vehicles axle weight load except for results from the short cable of the 3rd tower where lane 4 was affected by the loading category. Thus, sensors were placed according to the finding from the structural analysis.

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