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# IMPACT FACTORS ON MEDIUM SPAN BRIDGES DUE TO MULTIPLE VEHICLE PRESENCE

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*ABSTRACT*

*The Dynamic Amplification Factor for Bridges is of major concern in both their design and assessment. Research to date has focused on the single truck event. However, in many bridges the critical loading case is that of multiple truck presence on the deck. To accurately determine the dynamic amplification factor it is necessary to examine the effects of multiple trucks traversing a bridge. Experiments in Slovenia were carried out to examine the dynamic amplification factor for single and two truck events. Numerical models were constructed and validated from these experiments. These models were then used to compare the dynamic amplification factors produced from both single and multiple trucks crossing the bridge at various speeds. Important conclusions are drawn for bridge design and assessment purposes.*

## 1. INTRODUCTION

Dynamic Amplification Factors (DAF's) have a significant effect on the design and assessment of bridges and there is great potential benefit from rationalising the approach used by bridge engineers. The dynamic amplification factor is defined as the ratio of the combined response of the bridge (both static and dynamic) to the static response. Codes of practice commonly calculate amplification factors as a function of span length, but the interaction between bridge, trucks and road roughness involves many more parameters which are difficult to identify and allow for when attempting to determine the bridge response (DIVINE, 1997). Much of the research to date on this phenomenon has concentrated on the single truck event and has identified situations where 'frequency matching' can occur between the truck and the bridge (DIVINE, 1997). However, for a great many bridge the critical loading event involves more than one truck, in which case the amplification effects are substantially different. Knowledge of the response of a bridge to multiple truck crossing events is essential for an accurate calculation of the relevant amplification factor. This paper investigates the comparison of the DAF produced from a single truck and the two truck event. Experiments were conducted in Slovenia to examine the response of a simply supported bridge for both single and two truck events. The results from this were used to calibrate a finite element model (produced in MSC/NASTRAN). This model was used to examine the amplification factor of the bridge for various truck crossing scenarios.

## 2.1 SITE SETUP

The tests were carried out on a bridge over the Mura river in north-eastern Slovenia. The bridge is a 32 m long simply supported span and is part of a larger structure. Figure 1 shows a schematic of the bridge.

Fig. 1 – Schematic of instrumental bridge

It is of concrete slab-beam construction. It has a first natural frequency of 2.802 Hz and damping of 3%. The bridge was instrumented with 12 strain transducers. Six transducers were placed on the bridge beams underneath each lane. Each pair of transducers had a longitudinal spacing of 4m. Two axle detectors were placed in each road lane to record truck position and velocity. The vehicles used in the experiment consisted of one two axle and one three axle pre-weighed truck. The two axle truck had masses of 3460 kg and12900 kg on each axle, while the three axle truck had a front axle mass of 6240 kg and a tandem mass of 18220 kg.

## 2.2 EXPERIMENTAL PROCEDURE

Experiments were conducted to examine the DAF's produced for both single and two truck events. A total of 12 passes for both the two and three axle trucks crossing the bridge were carried out. In each case the truck was the only vehicle on the bridge. These passes were carried out for the trucks travelling in various directions and at three different speed ranges (slow, average, and fast). To examine the two truck event, data was recorded for 25 passes with the two trucks on the bridge simultaneously. The two trucks were travelling in opposite directions, again at various speeds and meeting at various longitudinal positions along the bridge span. Figure 2 shows the two trucks passing each other on the instrumented span. The effect of one truck being stationary on the bridge as the other truck crossed was examined with 12 passes of the three axle truck as the two axle truck remained stationary at midspan.

Fig. 2 – Two truck event

## 3.1 BRIDGE MODEL

The bridge was modelled in finite elements as a 32 m long simply supported plate-beam model. The main deck was modelled using plate elements and the beams were modelled using offset beam elements. Lateral stiffeners were included, again using offset beam elements. Figure 3 shows the first two natural frequencies of the bridge. The road surface profile is modelled as a random process as described by a power spectral density function (Yang & Lin 1995). The profile is classified according to the International Standards Organisation (ISO). (Wong 1993). In this case it is taken to have an ISO value of 'good'. The stress at various longitudinal positions along the beam is output.

Fig. 3- First mode shape (2.802 Hz), second mode shape (3.681 Hz)

## 3.2 TRUCK MODELS

The trucks were modelled as rigid frames in finite elements. They were represented as body mass and axles masses. The axle masses can move in the vertical direction while the body mass can move in the vertical direction and rotate. The body mass in both trucks is modelled as a frame consisting of bar elements. The suspension and tyres are modelled as a spring and dashpot system. The values of stiffness and damping are taken as typical values from the literature (Kirkegaard et al. 1997, Baumgartner 1998, Lutzenberger & Baumgartner 1999, Huhtala 1999). The trucks travel in opposite directions and at a constant velocity. Figure 4 shows a schematic of the three axle truck, the two axle truck being similar.

Fig. 4 - Schematic of the three axle truck represented in MSC/NASTRAN

## 3.3 Finite element dynamic interaction

The modelling of vehicles and bridges was carried out with the general purpose finite element analysis package MSC/NASTRAN for Windows, which provides the capability for performing a transient dynamic response (MSC/NASTRAN). A C++ program to perform simulations of truck models crossing a bridge has been developed. The program generates NASTRAN input code for any arbitrary one-dimensional or spatial bridge and vehicle model. The dynamic interaction of the bridge and vehicle incorporates a road surface profile and is implemented using a set of auxiliary functions to enforce the compatibility conditions at the bridge/vehicle interface (Cifuentes, 1989). The road roughness can be generated from theoretical power spectral density functions or real measurements. The speed/acceleration of the vehicles, their initial positions and paths on the bridge are also required. The input allows for the specification of simultaneous traffic events with vehicles running in the same or opposite directions.

The program generates an entry into the assembled stiffness matrix of the vehicle-bridge system. This entry allows the interaction forces "$F_j$" at the contact point of each wheel "$j$" on the bridge to be defined. A compatibility condition between the vertical displacement "$w_j(t)$" of the wheel "$j$" and the bridge at the contact point is also established at any time "$t$" as formulated in equation 1.

$$w_j(t) = \sum_i A_i(t) y_i(t) + \sum_i B_i(t) \theta_i(t) \qquad i=1,2,...N \tag{1}$$

where "$y_i(t)$" and "$\theta_i(t)$" are the displacement and rotation at each node "$i$", "$N$" is the total number of bridge nodes, and "$A_i(t)$" and "$B_i(t)$" are auxiliary functions. The auxiliary functions $A_i(t)$ and $B_i(t)$ can adopt different values at each node "$i$" for each instant "$t$". Their shape is shown in figure 5. They have zero value outside of the interval between adjacent nodes.

Figure 5 – Auxiliary function $A_i(t)$, auxiliary function $B_i(t)$

Finally, equation 2 illustrates the force "$f_i(t)$" and moment "$m_i(t)$" acting on a bridge node "$i$" at time "$t$" due to the interaction force "$F_j$" at each wheel "$j$".

$$\begin{Bmatrix} f_1 \\ m_1 \\ f_2 \\ m_2 \\ \cdot \\ \cdot \\ f_N \\ m_N \end{Bmatrix} = \begin{Bmatrix} A_1 \\ B_1 \\ A_2 \\ B_2 \\ \cdot \\ \cdot \\ A_N \\ B_N \end{Bmatrix}_1 * F_1 + ... + \begin{Bmatrix} A_1 \\ B_1 \\ A_2 \\ B_2 \\ \cdot \\ \cdot \\ A_N \\ B_N \end{Bmatrix}_r * F_r \tag{2}$$

where "$r$" is the total number of wheels on the bridge. The auxiliary functions "$A_i(t)$" and "$B_i(t)$" are different for each "$F_j$" due to the fact that each axle takes a different length of time to reach the same node and each wheel of a particular axle follows a different path on the bridge.

## 3.4 VERIFACTION OF FINITE ELEMENT MODEL

In order for analysis to be undertaken using NASTRAN it was first necessary to verify the bridge and truck models with the data collected in Slovenia. An accurate value of structural damping was determined using data collected by the axle detectors. Typical experimental data from a truck crossing was examined and the velocity of the truck determined. The corresponding simulation was than carried out in NASTRAN and the resultant responses compared. Figure 6 shows a typical match that was obtained for each of the single truck events.

Fig 6 – Comparison of measured and finite element responses

It can be seen from the figure that there is a reasonable match between the measured and finite element responses. It is hoped that through further work with the models, particularly in the area of suspension and tyre parameters these matches can be improved.

After each truck was verified separately a simulation of the two truck event was compared to a measured response. This is shown in figure 7.

Fig. 7 - Comparison of theoretical and measured responses for both trucks traversing the bridge at the same time

It was found that there was a reasonable comparison between the two responses illustrated in figure 7. It is important to note the right hand side of the graph in figure 7, this difference in vibration is most likely due to the actual suspension characteristics differing from those in the model. The authors plan to adjust parameters to achieve a closer match in the future.

## 4. THEORETICAL STUDY OF DYNAMIC AMPLIFACTION FACTORS

Simulations were carried out for the three axle truck traversing the bridge at various speeds from 10 – 80 km/hr. In each case the stress at the centre of the span is examined. Figure 8 shows both the static and the combined midspan stress response at 50 and 80 km/hr for the three axle truck. For low velocities the response of the bridges closely follows the path of the static response. However, as the velocity of the vehicle increases the level of dynamic interaction also increases as shown in figure 8.

Fig. 8 - Mid-span static response & combined response of bridge being traversed by three axle truck travelling at speeds of 50 & 80 km/hr

Similar simulations were carried out for the two trucks crossing the bridge simultaneously. The trucks were travelling in opposite directions and at the same speed. The two trucks met at mid-span, ie, the front axle of both the two axle and the three axle trucks were at mid-span. Figure 9 shows the static bridge response and the combined bridge response at various velocities for the two truck event.

Fig. 9 - Static & combined response of the bridge being traversed by both trucks at speeds of 50 & 80 km/hr

In each of the simulations the dynamic amplification factor was calculated and the factor for each of the single truck events were compared to that of the corresponding two truck event for various speeds, see figure 10. The values of amplification factor for the two truck event were determined using the assumption that the static response of the bridge for the two truck event was the superposition of the static responses of both the single truck events. This assumption is currently being investigated.

Fig. 10 - Dynamic Amplification Factors for single & two truck events for various velocities

As can be seen from the figure, the dynamic amplification factor with reference to velocity differs for each truck. The peaks in the graph for the single truck events occur at different velocities. For the two axle truck the maximum impact factor occurs at 70 km/hr with a value of 1.11. The maximum amplification factor for the three axle truck occurs at a velocity higher than 80 km/hr. A study of higher velocities should be carried out to determine the maximum impact factor for the three axle truck. The dynamic amplification factor for the two truck event for this particular bridge is generally lower than for the single truck events. This may be explained by a form of destructive interference occurring between the trucks.

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## TABLES & FIGURES

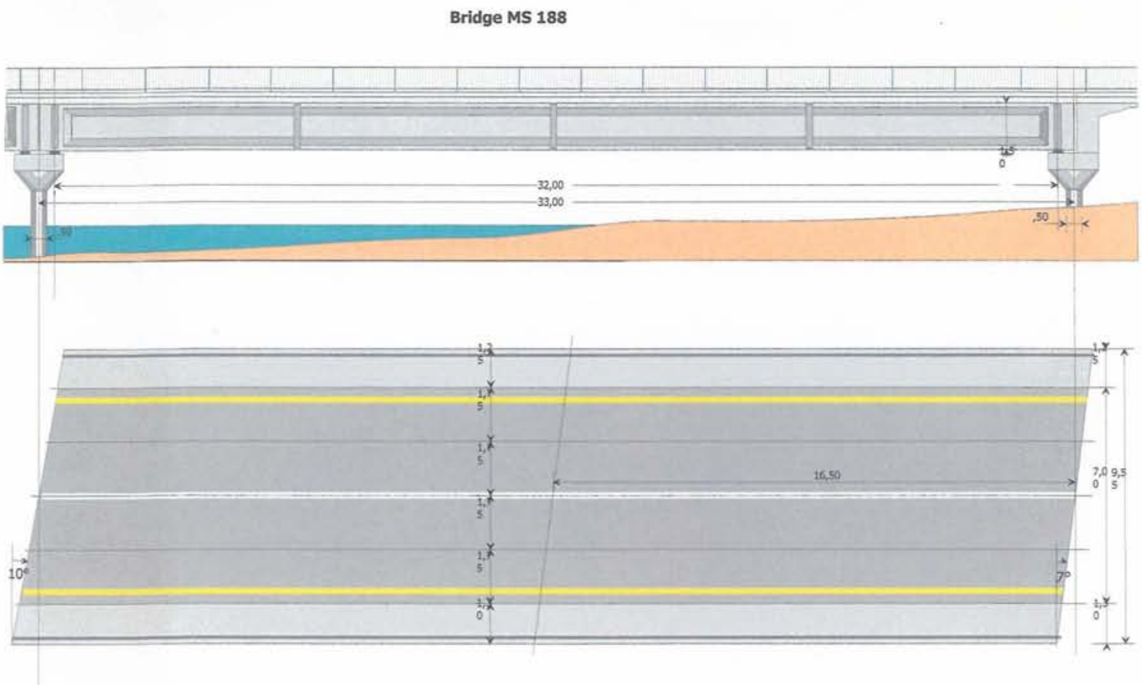



Fig. 1 – Schematic of instrumental bridge

Fig. 2 – Two truck event

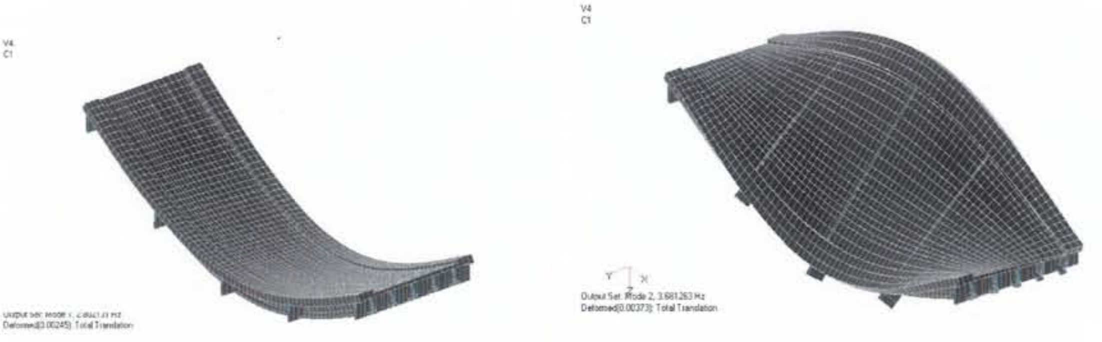


Fig. 3- First mode shape (2.802 Hz), second mode shape (3.681 Hz)

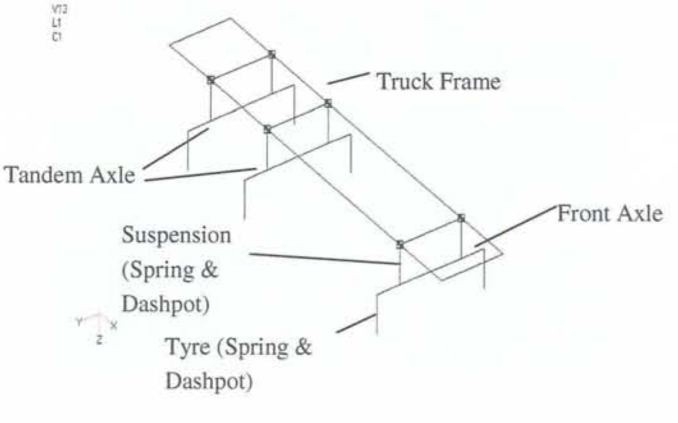



Fig. 4 - Schematic of the three axle truck represented in MSC/NASTRAN

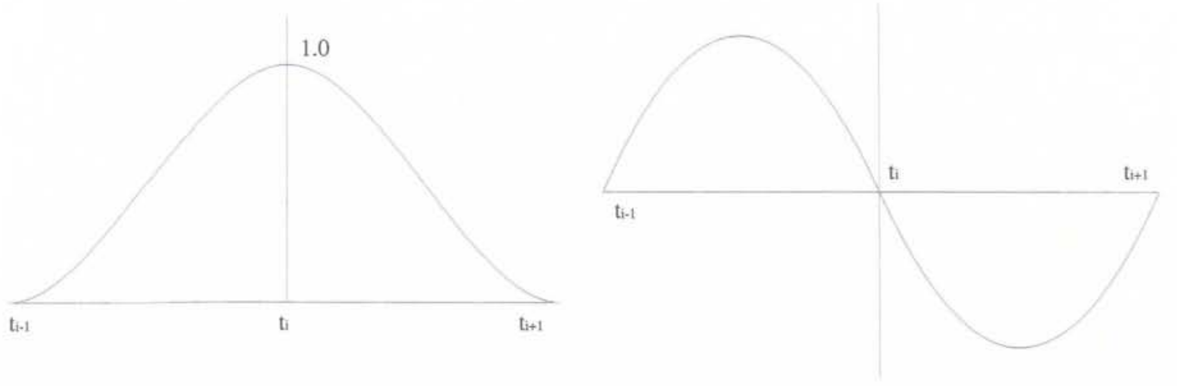
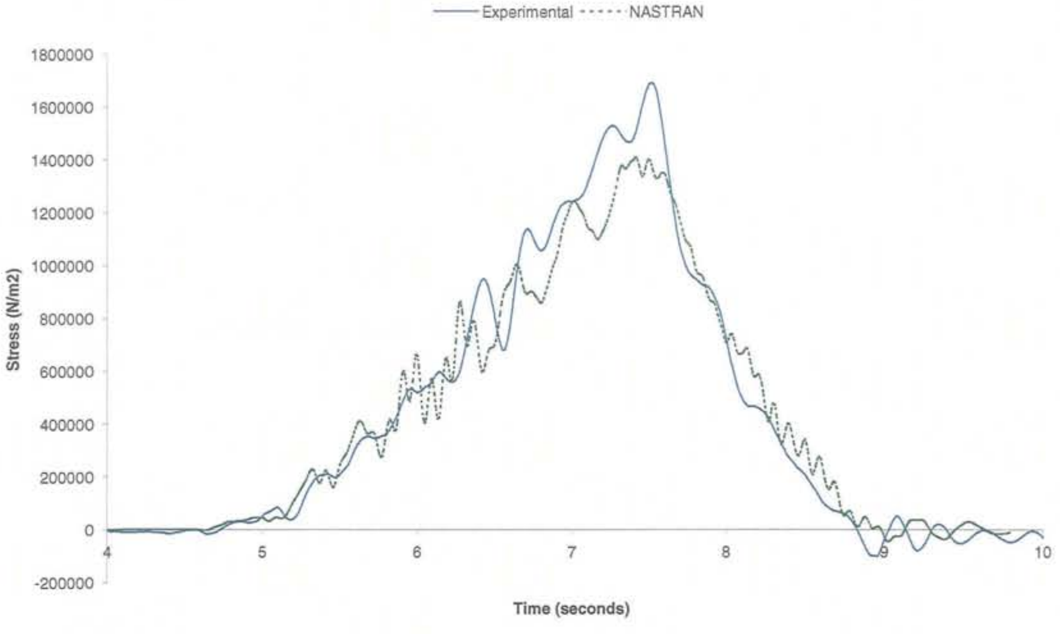
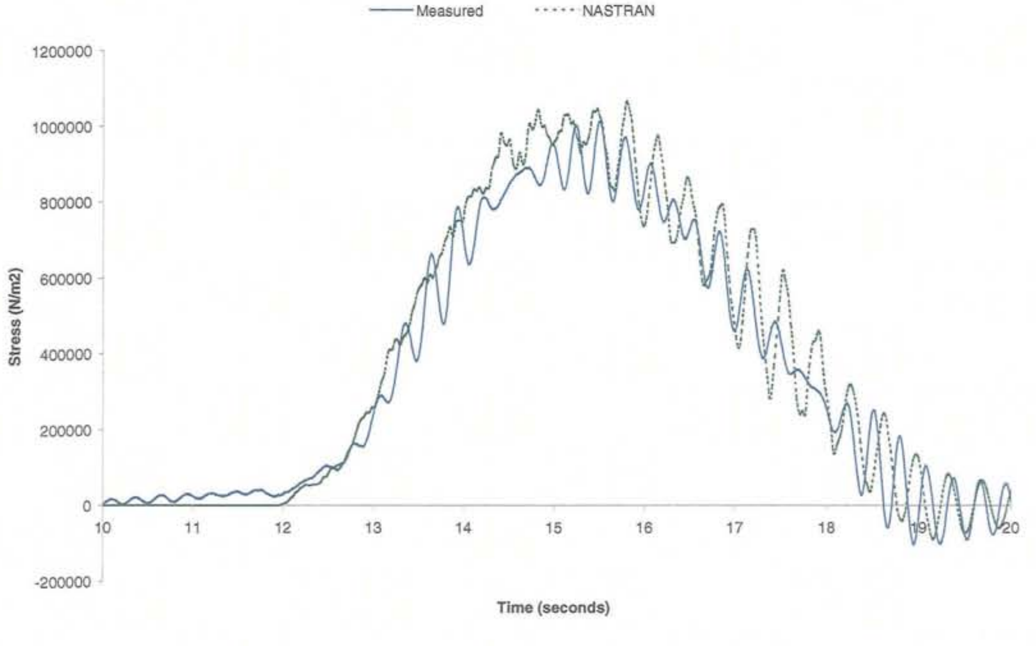



Figure 5 – Auxiliary function $A_i(t)$, *a*uxiliary function $B_i(t)$




2 axle truck




3 axle truck

Fig 6 – Comparison of measured and finite element responses

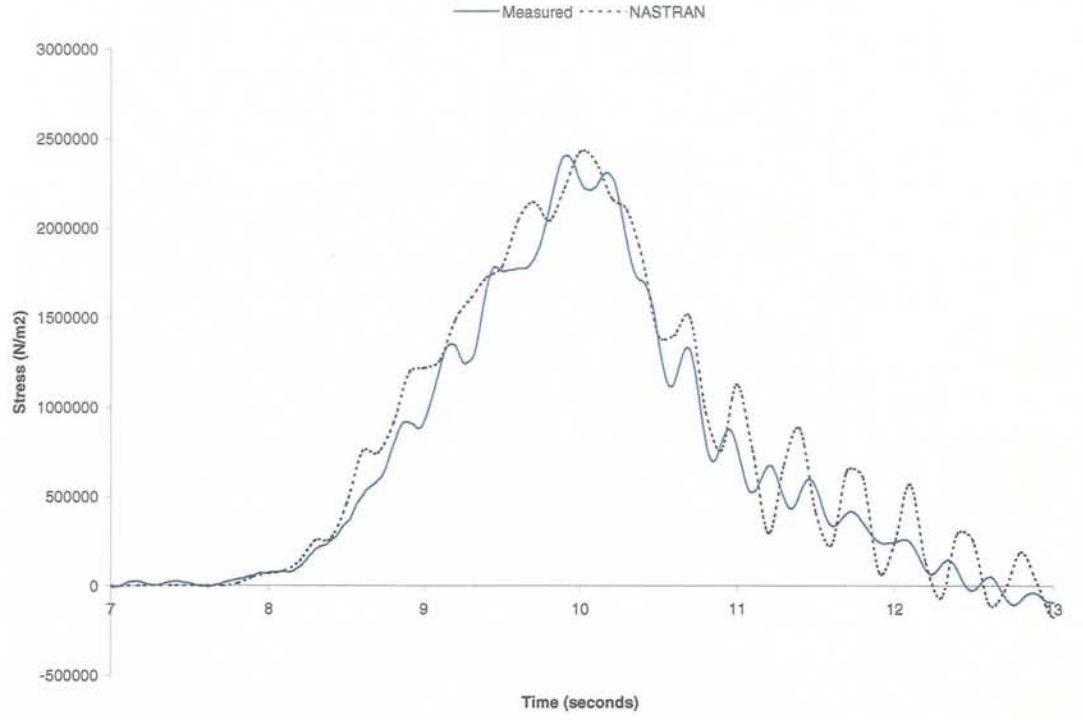



Fig. 7 - Comparison of theoretical and measured responses for both trucks traversing the bridge at the same time

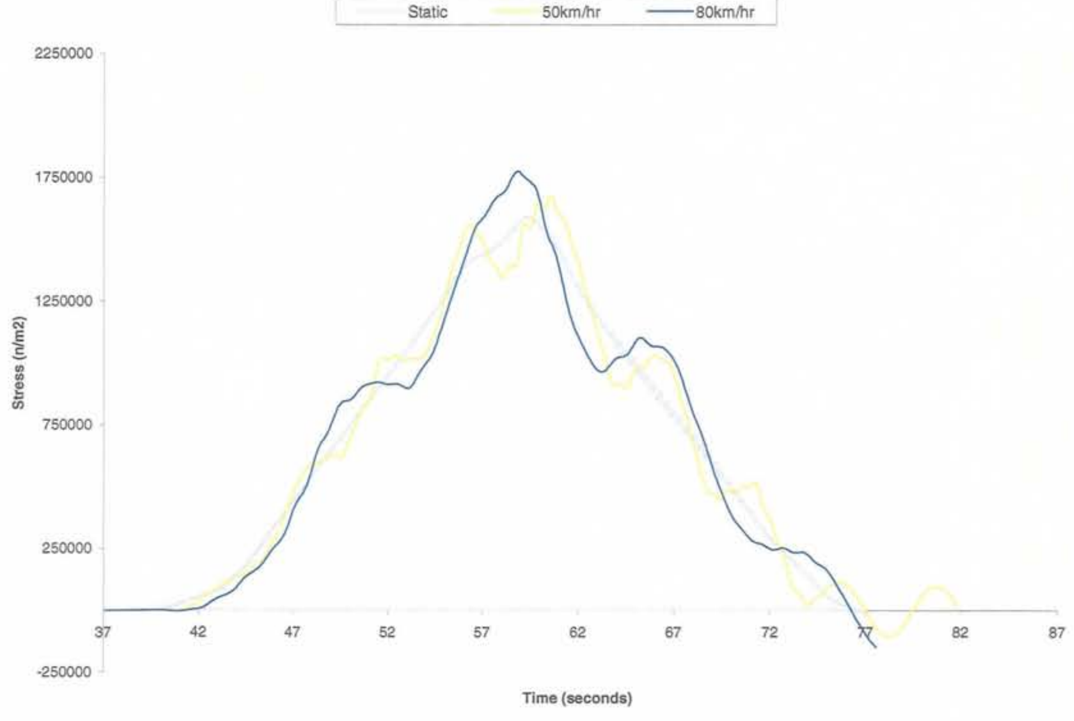



Fig. 8 - Mid-span static response & combined response of bridge being traversed by three axle truck travelling at speeds of 50 & 80 km/hr

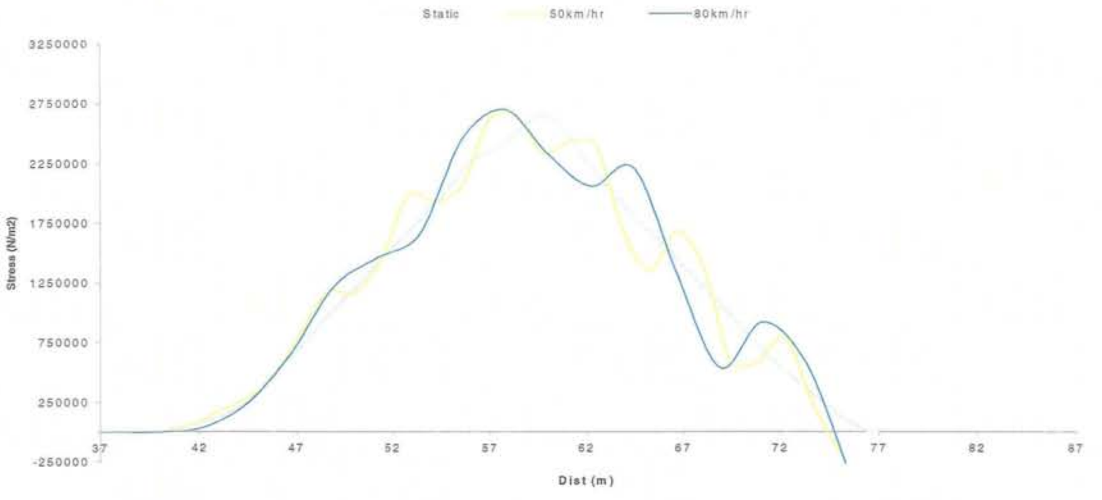



Fig. 9 - Static & combined response of the bridge being traversed by both trucks at speeds of 50 & 80 km/hr