

Overloading of Simply Supported Unseated Composite Bridges

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Abstract: Unseating of multi-girders composite bridges results in overloading of several structural elements. The unseating of the girders may be caused through different events such as earthquakes, fatigue failure of bearing or even in poor countries due to theft of bearings. This research concerns the time period during which the bridge is open to traffic before actual forbiddance of traffic crossing and starting rehabilitation where the overloading happening for seated girders especially the bearings and main girders. The seated bearings may suffer two or three times the design reaction value which necessitates a special concern. The increased deflection of seated main girders depends mainly on the relative stiffness of the end cross girders. This research concerned mainly the analysis of composite bridges composed of four and five main girders taking into considerations the effects of bridge span, relative stiffness of end cross girders and the distribution of cross girders within bridge span.

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1. Introduction

Bridge bearings are crucial components of highway networks and require both corrective and preventative maintenance actions. The author has presented a study for the effect of bridge girders unseating for a simply supported composite bridge composed of three main girders (**Matar 2012**). The study handled the change in straining actions (bending moments and shear forces) in main girders due to bridge unseating. A remarkable change of the straining actions was observed depending on the stiffness of end cross girder as well on the number of cross girders. The current research handles the study of composite bridges with four and five main girders and as well the effect of bridge unseating on the change of straining actions of main girders, seated bridge bearings and deflection of main girders.

In recent years, continuing aging and heavy utilization of many bridges have come into conflict with limited funds available in many countries. It has been reported that about 125,000 of the 585,000 bridges in the USA are deemed deficient. The bearings provide an interface between the superstructure and the substructure (**Brownjohn, Pin-Qi Xia, Hong Hao, Yong Xia 2001, Zhiye, Chuanyu 2002, Aditya, Chandra 2010**). A bridge is considered to be made up of two major parts, i.e. the superstructure and the substructure. Nonetheless, secondary components such as rubber bearings, hinge restrainers, side stoppers and expansion joints if not well taken care of are likely to result in undesirable overall performance of a bridge structure during extreme events (**Ching 2007**). Bearings and expansion joints are normally sources of deterioration problems (**McCrea, Chamberlain, Navon 2002**).

Bridge bearings failure may result from massive earthquakes, hurricanes, pounding, fatigue failure, accidents to bridge piers or even in poor countries due to theft of bearings. **Sang-Hyo, Ho-Seong, Sang-Woo (2006)**, mentioned that bridges supported by traditional fixed and movable bearings are likely to experience various types of damage during seismic excitations. The bearings that support the superstructure of a bridge appear to be the weakest link in structural resistance to seismic loads in the past earthquake records. The damage of bearings may change the seismic responses of both superstructures and substructures of the bridge system. Because of the insufficient design for seismic resistance, bearings can be easily damaged by inertia force of the superstructure or by pounding forces between adjacent superstructures underground motions. Compared to the results from a system without the occurrence of damaged bearings, the response results are in quite different shapes in the systems with damaged fixed and movable bearings. It was reported that nearly 45 bridges sustained damage in Alabama, Louisiana, and Mississippi during Hurricane Katrina (**Jamie, Reginald, Bryant, Mark, Oh-Sung, Nick; et.al. 2008**). Most of the damaged bridges were adjacent to water with damage resulting from storm surge-induced loading. Much of the damage was to the superstructures, where typical damage included unseating or drifting of bridge cross section. **Shehata (2009)**, reported that expansion joints may be a weak point in an isolated bridge where a large relative displacement anticipated at an expansion joint in a standard bridge under a design ground motion that could reach many times the standard clearance between decks. Such large relative displacements

between the adjacent girders can not only cause poundings, but it could play major role in bearing damage, hence unseating failure of a bridge system and subsequent collapse. **Masahiro, Toshimitsu, Mizuhiro, Turgay (2000)**, reported that during the renovation and widening project for the Golden Horn Bridge in Istanbul, Turkey, that carried out on the concrete superstructure of the bridge constructed in the early 1970s, local settlement of 15cm and large cracks on the underside of the superstructure were observed. Upon inspection of the bearing on that pier, it was found that the cylinder of a bearing roller had split in half along its longitudinal axis. After further investigation, it was found that the splitting failure in the roller occurred due to fatigue and material problems

Davidson, Yoo, (1991), reported about a Fourier series expansion that have been used to obtain the deflection, moment, shear, velocity, and acceleration expressions for a multi-spans highway bridge superstructure under the effects of vertical support motion. A finite element analysis is used to help verify the results. Other studies handled the effect of cross frames on the static behavior of steel girder bridges without studying the effect of bridge unseating. For example **Azzinamini, Pavel, Lotfi (1996)**, studied the influence of cross frames on the seismic performance of straight steel I girder bridges. A two spans continuous composite bridge consisting of five hunched girders with two different types of cross frames, X frames and K frames was analyzed using SAP 90. It was concluded that the differences in behavior between X and K cross frames were negligible. **Maneetes (2003)**, carried out a parametric study using finite elements modeling using ABAQUS. It was concluded that the combination of results from natural frequencies, stresses and displacements indicated that, for this structure, although certain parameters for X-type cross frames were higher than those for K-type frames, the behavior of the two systems could be considered nearly identical. **Yannick, Gerard, Philippe, Jullien (2006)**, investigated the effect of diaphragms on the behavior of composite multi-girders steel bridge and indicates that the contribution of the diaphragms is not really known.

2. Objectives

The literature survey indicates that only a few studies have been conducted to quantify the effect of bridge bearing loss on the behavior of the bridge. The study concerns the behavior of unseated bridge during the time period between unseating of one of the bridge bearings and the actual forbiddance of traffic passage on the bridge. This time period may be just few hours in first world countries and may extend to days, weeks or even months in poor countries. The

objective of this research is to study the effect of unseating of composite bridges composed of four and five main girders and study the effect of the different parameters on the change of straining actions not only for main girders but as well on bridge bearings and deflections of main girders. The parameters included in this study are the bridge span length, number of main girders in the cross section, distribution of cross girders within span length of bridge, relative stiffness of end cross girders to main girders. The effect of these parameters on the straining actions concerning bending moments at mid spans, shear forces at unseated region, deflection of main girders at mid span and reaction on supports nearby unseated main girders are presented.

3. Variables range in the parametric study

Figure 1 illustrates a typical layout for a bridge with cross girders at quarter points, with the supports distribution for four and five main girders (reference of layout for three main girders is found in **(Matar 2012)**). The distance between the exterior main girders were kept constant and the distance between the main girders were varied depending on the number of main girders. A preliminary design was carried out for the bridge to determine the main girders cross section before modeling. Then, a grillage analysis **(Richard, 2007)** was manipulated to model the bridge main girders and cross girders as 3D frame elements and the deck slab as shell elements using commercial software Sap2000. The bridge was covered with a layer of asphalt of 10cm and the live loads used in this study composed of two lanes with two trucks 600 KN and 300 KN (loads not including impact factor) with the associated uniform loading as shown in Fig. 2. Each main girder was loaded to find the maximum straining actions acting on it before and after unseating. Each bridge case was given a unique symbol indicating statical system of bridge i.e. no. of spans, bridge span in meters, number of main girders, spacing of intermediate cross girders and relative stiffness of end cross frame to steel main girder. For example C1-36-4-L2-04 indicates composite bridge of single span (C1) with 36 m span composed of four main girders and cross girders arranged at half span with relative stiffness of end cross frame to steel main girder of 0.4.

The variables studied and their ranges are as indicated in table 1. In this study, the slab thickness was constant for all cases equal to 200mm. The relative stiffness of intermediate cross girders were kept constant equal to 0.1 except for the case of $I_{exg}/I_{MG}=0.05$ where in this case it was taken same as for end cross girder.

Table 1:- list of parameters and its range in this study

No.	Variable	Range	Note
1	Bridge span (L)	24, 36 and 48m	Default value 36m
2	No. of main girders	4 and 5 main girders	Data for 3 main girders are available (Matar 2012)
3	Spacing of cross girders	Equally spaced, every L/2, L/4 and L/8	Symbolized L2,L4, L8
4	Relative stiffness of end cross girder (XG2) to steel main girder (I_{exg}/I_{Mg})	0.05, 0.1, 0.25, 0.4, 0.7 and 1.0	Symbolized 005, 01, 025, 04, 07, 10
5	Unseated supports	Independently, supp.1, supp.2 for main girders	

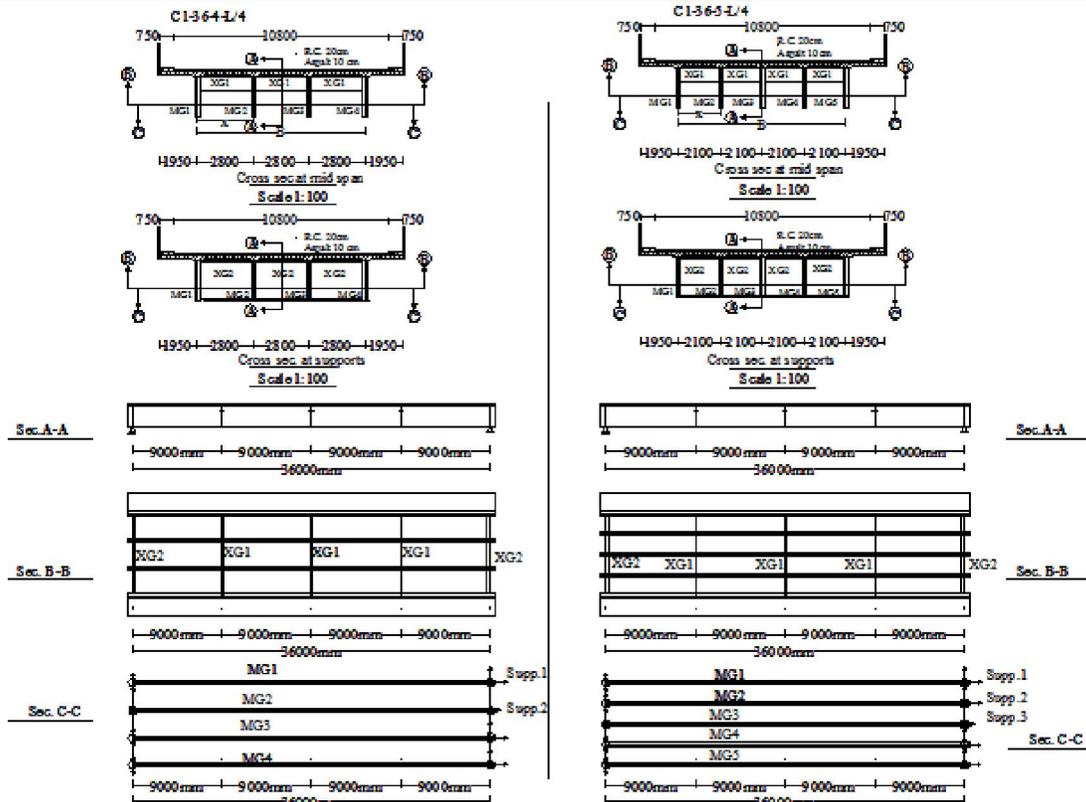


Fig. 1: Examples of cross sections of simply supported composite bridges

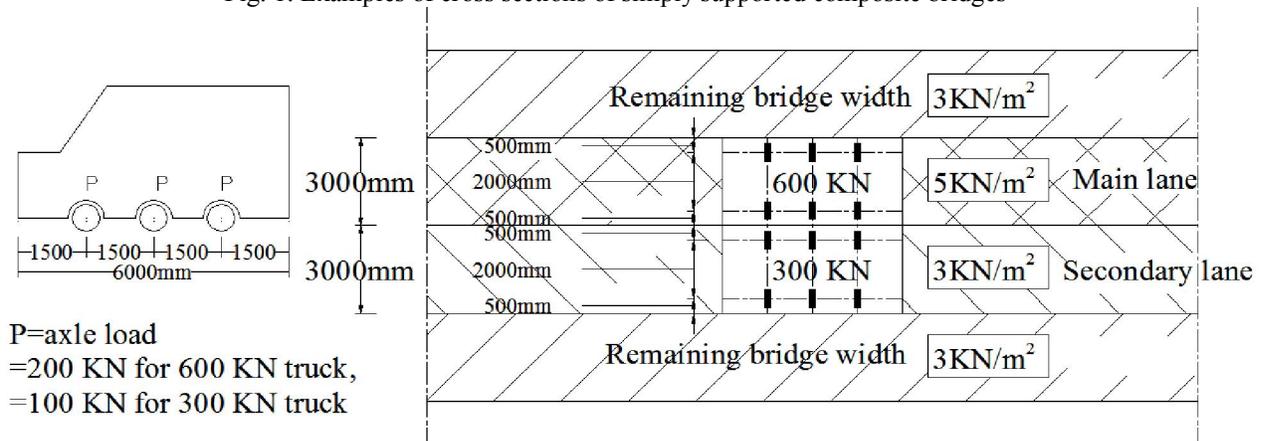


Fig. 2: A plateau for the live loads used in bridge loading

4. Discussion of the results of the parametric study

A large amount of data has been generated following the grillage analysis and therefore, only some representative trends of the results will be submitted in this paper. The effect of the different parameters will be discussed on the straining actions taking into consideration that the live loading to get the maximum straining actions will be chosen to get the maximum design values on the unseated girders.

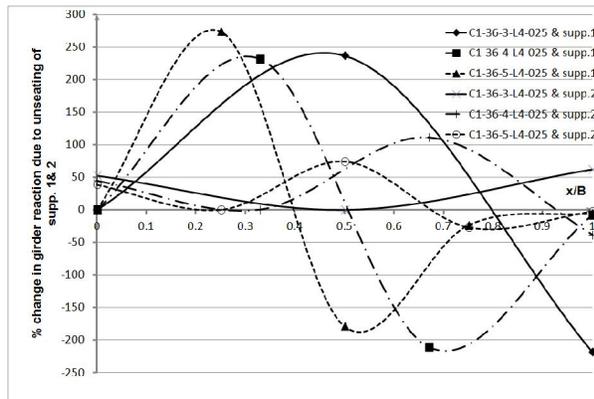


Fig. 3 Percentage change in bearings reactions due to unseating of supp.1, supp.2 for three, four and five main girders

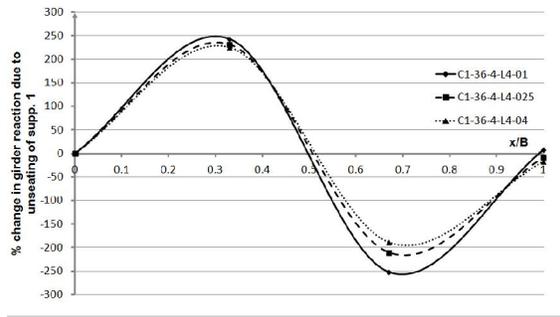
4.1 Effect of main girders unseating on the bearings reaction

The effect of unseating on adjacent bearings reaction is illustrated in Figs. 3 through 5. Figure 3 illustrates the comparison between the percentage increases in bearing reactions during bridge unseating for different bridge cross sections. The horizontal axis represents in the following figures, the ratio of the distance (x) from interior girder to the first exterior girder divided by the distance between exterior girders (B). As shown in Fig. 3, it was observed that when unseating supp. 1 an increase/ decrease (compression (+)/ tension (-)) of nearly about +250%/-200% for the first interior girder and for other girders respectively. Both of extra compression or tension should be taken into consideration during design. When the second support (supp. 2) was unseated, lower percentages of changes in the adjacent bearing reactions were observed (percentage change ranged between -40% to +110%) depending on the number of main girders within bridge cross section. The difference in %age change in bearing reactions due to unseating of exterior or interior supports is referred to the fact that when exterior bearing is unseated, in addition to the vertical load transferred to the adjacent bearing, the eccentricity in vertical load transfer increases the percentage change while for unseating of intermediate bearing, the

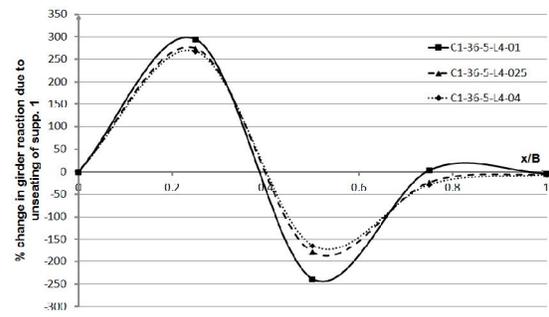
vertical load is distributed in between adjacent bearings with nearly no eccentricity and therefore lower percentage change.

Figures 4 and 5 represents the relationship between the percentage change of bearings reactions due to unseating of one bearing and relative stiffness of end cross frame to main girders for different values of spans for a bridge composed of four and five main girders. For a bridge composed of four main girders and as shown in Fig. 4(a), the percentage increase and decrease in the bearings reactions (2nd and 3rd bearing) due to unseating of 1st bearing may range between $\pm 250\%$ for the case of relative stiffness of end cross frame of 0.01 and this percentage decreases with the increase of the relative stiffness of end cross frame. The farthest bearing (last exterior one away from unseated bearing) is the least one to be affected with bridge unseating. However, similar behavior was observed for a bridge composed of five main girders, but the percentage increase and decrease was ranged between +300% to -250% for 2nd and 3rd bearings respectively as shown in Fig. 5(a). When the 2nd bearing was unseated, for a bridge composed of four main girders, both of the 1st bearing and the 3rd one recorded an increase ranged between nearly 50% and 110% respectively. However, the smaller increase in the first bearing referred to the fact that already the loading was heavier for the first main girder than that for the third for live loading positioning of trucks within bridge cross section and therefore the percentage increase for the first was less than that recorded for the third main girder. Similar behavior was observed for a composite bridge composed of five main girders but the increase ranged between nearly 50% and 80% for the first and third bearing respectively. The change of relative stiffness of the end cross frame for unseating of the second bearing (supp.2) shows minor effect for a bridge composed of four main girders.

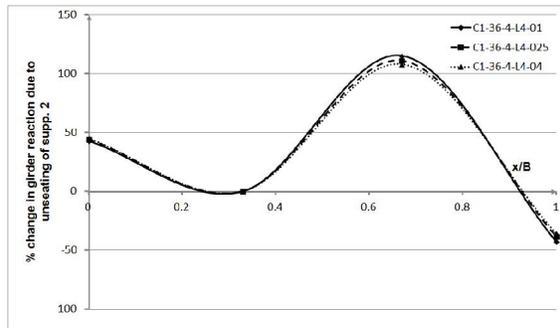
When the bridge spans were investigated, it was observed that shorter span bridges suffering larger changes in bridge bearing reactions than longer span bridges whether for a bridge composed of four or five main girders. For example for a bridge composed of five main girders as shown in Fig. 5(c) the percentage increase in the 2nd bearing reaction due to unseating of supp. 1 at spans of 24m and 48m were nearly 325% and 230% respectively. This may be attributed to the fact that dead load in longer span bridge have a remarkable percentage of the total reaction in the bearing and therefore, a change for the live load fraction due to unseating will not possess a larger effect as happened in shorter span bridges.



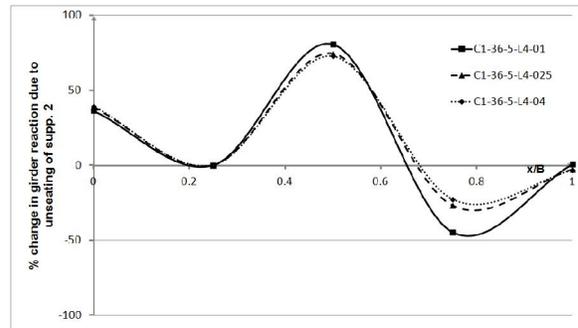
(a)



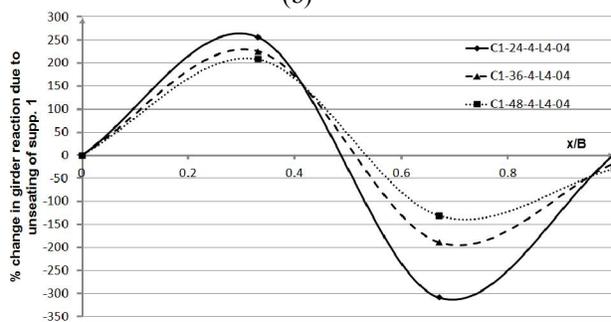
(a)



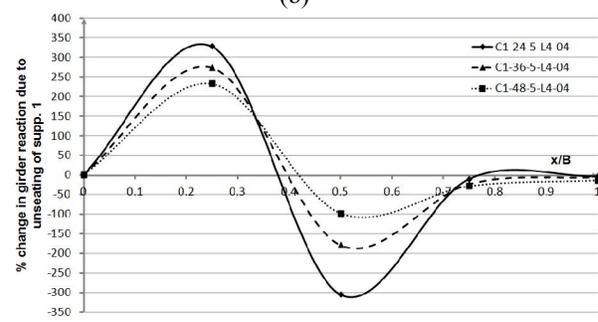
(b)



(b)



(c)



(c)

Fig. 4 Percentage change of bridge bearings reactions due to unseating of MG1 and MG2 for composite bridge with four main girders for different values of spans and ratio of I_{cxg}/I_{Mg}

Fig. 5 Percentage change of bridge bearings reactions due to unseating of MG1 and MG2 for composite bridge with five main girders for different values of spans and ratio of I_{cxg}/I_{Mg}

4.2 Effect of main girders unseating on the deflection of main girders at mid span

The effect of main girders unseating on the deflection at mid span for different main girders is shown in Figs. 6 through 8. Focus on deflection will be given to the case of unseating of supp. 1 as it yields remarkable %age change in deflection than other supports as will be proved. In figure 6, unseating of MG1 (loosing supp. 1) resulted in an increase of deflection for the unseated girder of nearly about 17% for a bridge composed of three main girders while this value is decreased to less than or equal 5% with the increase of the number of main girders to four and five main girders. On the other hand we have uplift on the furthest exterior girder for

all bridge cross sections as shown in Fig.6. Smaller and neglected change in deflections was associated with unseating of MG2 (i.e. losing supp. 2) due to the distribution of the loads on adjacent two main girders which reduce the percentage increase in deflection and this reduction in percentage increase is more pronounced in composite bridge with larger number of main girders. In Figure 7(a) the percentage increase in mid span deflection for the four main girders composing the bridge due to unseating for exterior main girder is shown for different values of relative stiffness of end cross frame. The maximum increase of mid span deflection occurred at the unseated main girder and ranged between 4 and 9% depending on relative stiffness of end cross frame.

The larger the relative stiffness of end cross girder, the lower the percentage increase in mid span deflection. On the other side the shorter the span the remarkable increase in mid span deflection especially for the unseated girder. For example in Fig. 7(b) it was observed that for the same unseated exterior girder; there was an increase of nearly 2% for 48m bridge compared to 12.5% increase for 24m bridge span. Similar behavior was observed for the case of composite bridge composed of five main girders as shown in Fig. 8 for different spans.

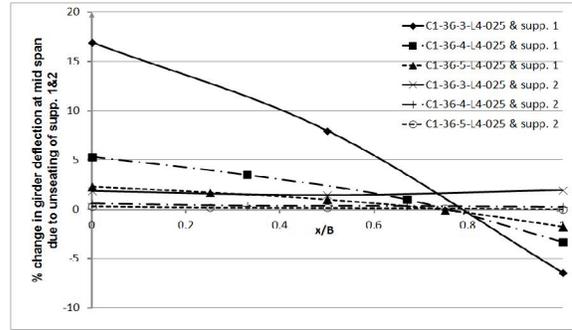
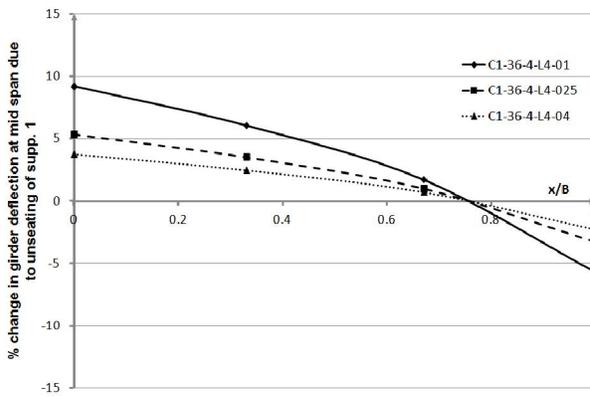
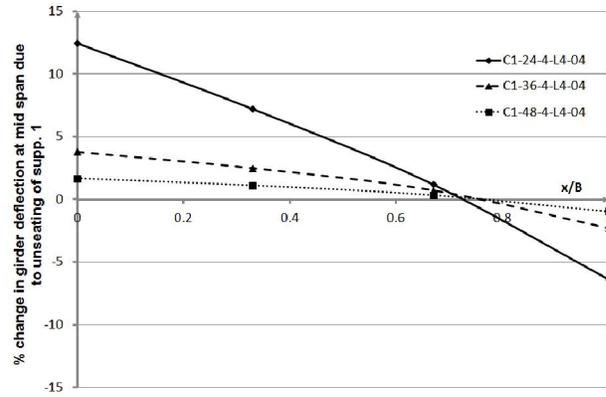


Fig. 6 Percentage change in mid span deflection due to unseating of supp.1 & supp. 2 for three, four and five main girders.



(a)



(b)

Fig. 7 Percentage change in mid span deflection due to unseating of support 1 for different values of relative stiffness of end cross frames and different spans of composite bridge with four main girders

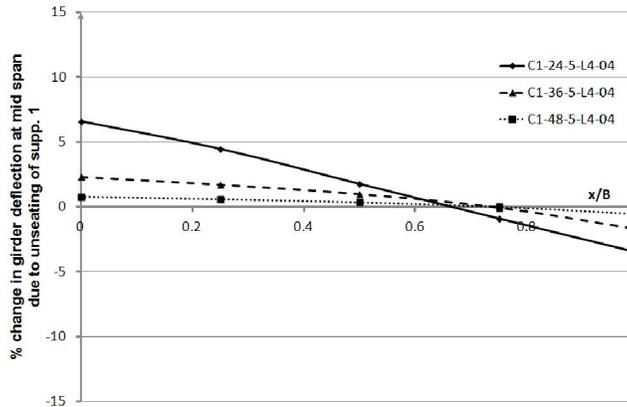
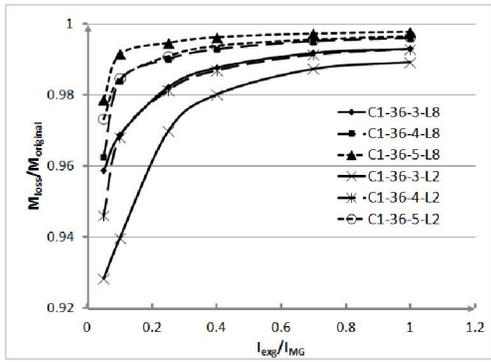
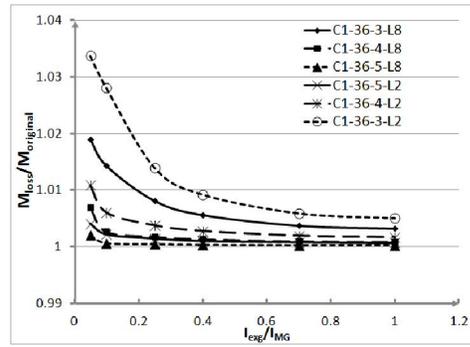


Fig. 8 Percentage change in mid span deflection due to unseating of support 1 for different values of spans of composite bridge with five main girders

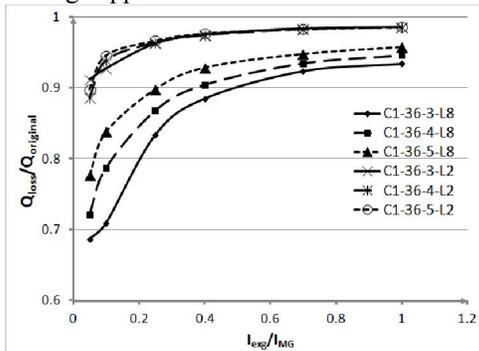
4.3 Effect of the number of main girders



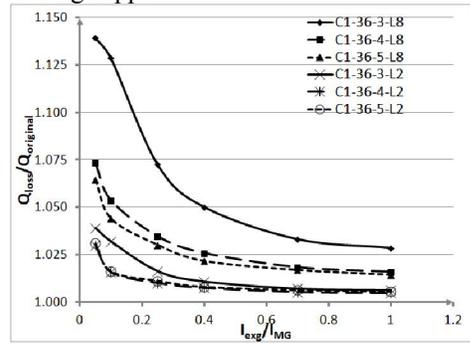
(a) ratio of changes in Moments in MG1 due to losing supp.1



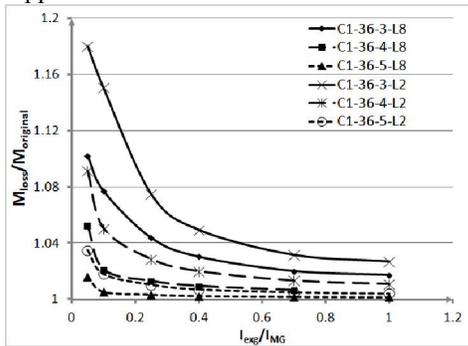
(e) ratio of changes in Moments in MG1 due to losing supp.2



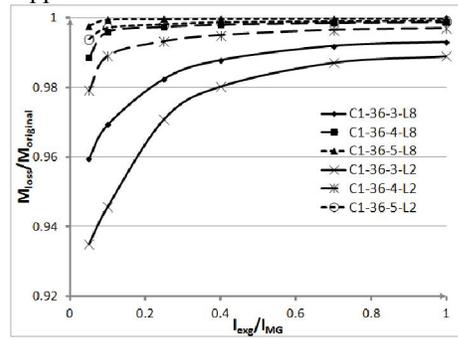
(b) ratio of changes in shear in MG1 due to losing supp. 1



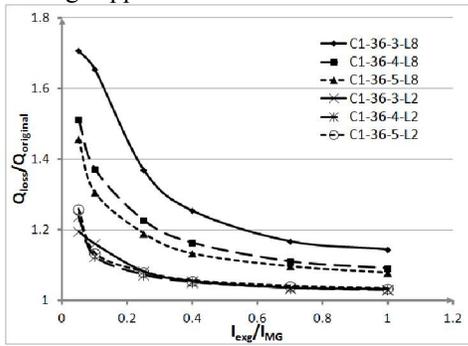
(f) ratio of changes in shear in MG1 due to losing supp. 2



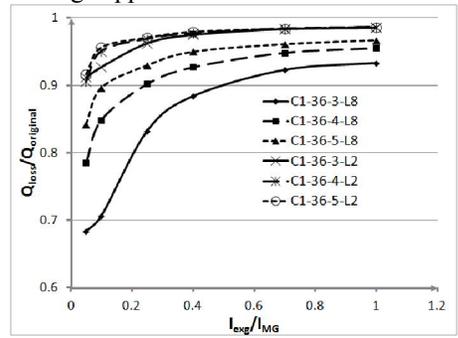
(c) ratio of changes in Moments in MG2 due to losing supp.1



(g) ratio of changes in Moments in MG2 due to losing supp.2



(d) ratio of changes in shear in MG2 due to losing supp. 1



(h) ratio of changes in shear in MG2 due to losing supp. 2

Fig. 9 changes in straining actions for different bridge cross sections due to unseating supp. 1&2

As mentioned in the parameters listed in table 1, that the number of main girders was varied maintaining the distance between the exterior girders is constant. Therefore, four and five main girders were analyzed and a comparison was carried out as shown in Fig. 9 for the effect of loosening either support 1 or support 2 on the adjacent girder for two cases of the spacing of cross girders which are $L/8$ and $L/2$. Just to fully understand the effect of the number of main girders, additional data was extracted from the analysis of composite bridge with three main girders (Matar 2012). In Fig. 9 (a) through (d) the effect of unseating of supp.1 on the straining actions of exterior main girder (MG1) and adjacent interior girder (MG2) was investigated for different values of relative stiffness of end cross girder and for different bridge cross section. It would be observed in these figures that the reduction of bending moments in MG1 due to unseating of supp. 1 is reduced with the increase of the relative stiffness of end cross girder and with the increase of the number of main girders within the bridge cross section. For example, while for C1-36-3-L2 at I_{exg}/I_{MG} of 0.05 we have reduction of bending moments of nearly 7.5% this reduction is reduced to nearly 1.5% at I_{exg}/I_{MG} of 0.7. On the other hand, the reduction in bending moments for the same bridge with cross girders arranged every $L/2$ is larger than that for a similar bridge with cross girders arranged every $L/8$ due to better distribution of bending moments in between main girders. The reduction of bending moments was smaller if larger number of main girders is used as for example when comparing C1-36-3-L2 and C1-36-5-L2. Similar behavior was observed for shear forces in MG1. The ratio of increase of bending moments in MG2 due to unseating of supp. 1 depends on the same factors i.e. the larger increase in bending moments was associated with lower value of relative stiffness of end cross girder, lower number of main girders within bridge cross section and finally lower number of intermediate cross girders. The percentage increase in bending moments ranged between less than 1% to nearly 18% depending on the above mentioned factors. The percentage increase in shearing forces ranged between 3% and nearly 75% depending on these three factors. On the other hand, unseating supp. 2 yields similar increases in adjacent girders and decrease in unseated main girder but with smaller ratios due to the fact that the straining actions are distributed on adjacent main girders on both sides of the unseated interior girder as shown in Fig.9 (e) through (h). For example the percentage increase on bending moments for MG1 due to unseating of supp. 2 ranged between less than 1% to maximum of 3.5% while this increase in shearing forces ranged between less than 1% to less than 15%. The increase again

depends on the same three factors mentioned in unseating supp. 1. The rate of change of straining actions reduces after the relative stiffness of end cross girders exceeds nearly 0.4.

5. Conclusions

Based on the range of parameters studied and the analysis performed for different cases, it would be concluded the following:-

- 1- Unseating of exterior bearings results in an increase of adjacent bearing for first interior bearing by nearly +250% while for the next bearing the change was reverted to nearly -200%.
- 2- Unseating of interior bearing results in an increase of the adjacent two bearings by a ratio between +50% and 110% depending number of main girders composing the bridge while the farthest bearing would suffering tension that may reach -40%.
- 3- The larger the increase in end cross girder relative stiffness the smaller the percentage increase in seated bearing reactions and mid span deflection of main girders
- 4- The larger the bridge span, the smaller the percentage increase in both of seated bearing reactions and main girder mid span deflection.
- 5- The closer spacing of intermediate cross girders reduces the percentage increase/ decrease in straining actions in main girders during unseating due to better distribution of loads for increasing of transverse bridge stiffness.
- 6- It would be suggested to use a value of the relative stiffness of end cross girders to steel main girders of nearly 0.4 where beyond this value smaller benefits are gained for extra increase of relative stiffness.
- 7- Bridge designers should pay attention to the accidental load cases that may happen during bridge unseating specially in the design of bridge bearings and main girders.

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