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Structural Response of Panel Bridges For Different Configurations:A Comparative Analysis

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Abstract

This work presents a numerical comparative structural analysis of Panel bridges for different panel member configurations as well as panel arrangement, in which the main objective is to evaluate the effects of Panel shapes and Panel arrangement on structural response of Panel bridges. Panel bridges are modular bridge systems composed of steel panels connected together by pins and flexible in their behavior. These flexible systems of the panel bridges are more susceptible to dynamic loading. Four panels of different member configurations (Bailey, Delta, Cross, Liberty) as well as six bridges models for different panel arrangements (Single-Single reinforced (SSR), Double-single reinforced (DSR), Triple -single reinforced (TSR), Quadrupole-single reinforced (QSR), Double-Double reinforced (DDR), Triple-single reinforced (TDR)) were modelled in CSI Bridge and pushover analysis has been carried out in order to determine the collapse load capacity of each panel as well as bridges. Also, different real scale bridges have been modeled considering different panel member configurations as well as for different panel arrangement. In order to compare the maximum structural responses as function of the main variations considered, time history analysis is performed for all the structures considering dynamic loading. The study reveals that cross panel has greater collapse load capacity and stacking panels in vertical direction increases load carrying capacity and decreases mid span deflection significantly.

Keywords

Panel Bridges, Dynamic loading, Pushover Analysis,Time history Analysis

1. Introduction

Modular Panel Bridges are bridge system composed of steel panels connected together by pins, that utilizes a steel superstructure, is fabricated into modules and can be quickly installed in the field[1]. The modular bridges of Bailey type were the first developed panel bridges.They are developed during World War II to be used as logistical bridges with a recognized structural efficiency that has allowed them to be durable with slight geometric adjustments and improved class of materials and accessories.In the past, various forms of construction for the panels were considered, for example, bracing in the form of an M, N or K between the top and bottom chords. The final version used two rolled steel channels for both top and bottom chords, welded either side of rolled steel joist vertical web members and diamond bracing members[2].

Although Bailey bridges are early developed panel bridge, other different types of panel bridges can be also seen nowadays. They are Delta panel bridge, liberty panel bridges etc. Panel bridges are also often built to replace damaged bridges due to earthquakes, floods, or hurricanes and act as temporary structures during construction but nowadays it can be seen as a permanent structure too. However, the ultimate load-carrying capacity and behavior of the Panel bridges are unavailable in the public literature[3]. Since it is pre-fabricated in factories, no any design is done according to site conditions. If proper layout of panels is not deployed according to site conditions,it may fail quickly as they are constructed. Many panel bridges collapse due to overloading, negligence during construction and many other reasons. No new research literature can be found even though many fatalities has been occurred. For reducing these fatalities, load carrying capacity of panels and behavior of panel bridges on actual loading conditions has to be known. Various shapes of Panels i.e., Bailey, Delta, Cross and Liberty panel are utilized here to determine collapse load capacity of each panel. Also, real scale models of panel bridges with different panel shapes and different panels arrangement have been incorporated in order to investigate the structural response of bridges on vehicle as well as seismic loading conditions. It is helpful and beneficial to understand the true behavior of the Panel bridges for transportation and military engineering.

2. Methodology

A finite element analytical models representing real scale panel i.e., Bailey panel, Delta panel, Liberty panel, Cross panel were modeled in ETABS. Pushover analysis has been performed in order to evaluate the collapse load capacity of each panel. Also, single lane extra width panel bridge has been modeled considering above different panels along with different panels arrangements i.e., Single-Single Reinforced(SSR), Double-Single Reinforced(DSR), Triple-Single Reinforced(TSR), Quadruple-single Reinforced(QSR), Double-Double Reinforced(DDR) and Triple-Double Reinforced(TDR) in CSI Bridge for Bailey panels since they are widely used among all. Pushover analysis has been performed in order to determine the ultimate load carrying capacity of bridges for different arrangement of panels. Also, time history analysis has been performed in order to evaluate the structural performance considering ground motion in all three orthogonal directions. Also, influence of vertical component of ground motion over horizontal component of ground motion on structural response of bridges has been evaluated.

3. Modeling

Four different types of panels i.e., Bailey, Delta, Liberty and cross were modeled in ETABS. All the Section, their sizes, thickness were used from real Bailey bridge based on structural drawings from department of public works and highways, republic of the Philippines[4]. All the panels have its dimension 10'x5' and material used was steel of grade Fe345. Also, 30 m single span extra width (4.2 m) Panel bridge considering above panels and different panels arrangement have been modeled in CSI bridge. Different sections used in modeling bridges are illustrated in table 1.

Table 1: Section Details

Member	Size	Thickness
Chord(C)	4"x2"	5mmx7mm
Column(C)	3"x1.5"	5mmx7mm
Bracing(C)	3"x1.5"	6mmx8mm
Rakers(C)	3"x1.5"	6mmx8mm
Transom(I)	12"x4.5"	9mmx9mm
Stringer(I)	90mmx67mm	4mmx5mm
End post(C)	4"x2"	5mmx5mm
Bracing(L)	1"x1"	8mmx8mm
Sway brace(Bar)	25mm	
Plate(Shell)		6.5mm

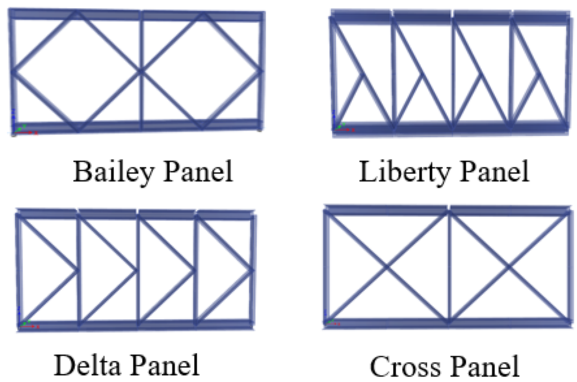

Figure 1: Different configuration of panels

CSI Bridge being the most powerful finite element tool, it also has some limitations to modeling tiny details which is required in modeling these panel bridges. So, to overcome this issue, for modeling inter-panel connections as in real scenario, rigid elastic link has been used. Also, all the inter panel joints are considered as pin jointed connections and these connections are modeled using section designer.

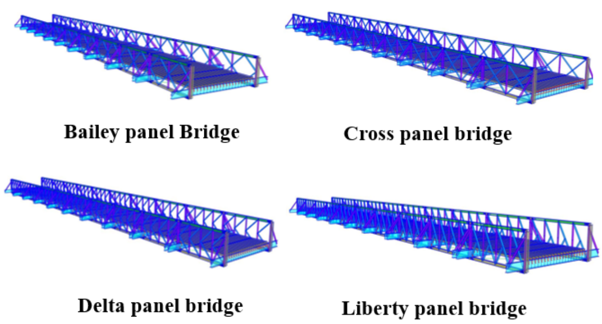

Figure 2: Different Panel Bridges

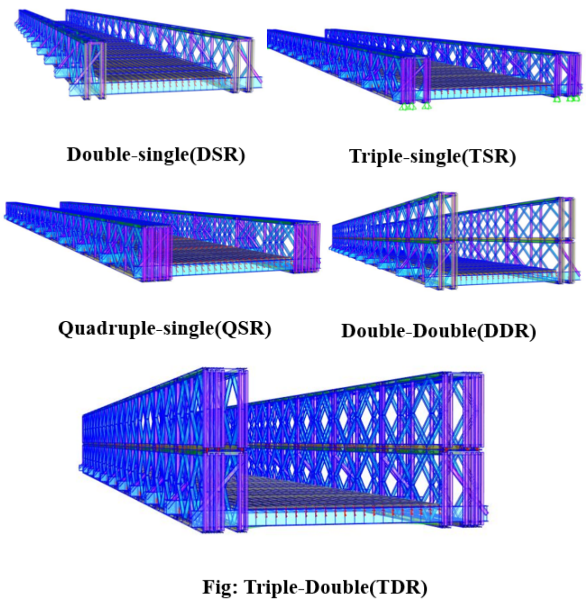

Figure 3: Different arrangement of panels

Here, IRC class B vehicle loading has been applied in four base model bridge with different panels and for bridge with different panel arrangements, IRC class A loading has been used. Also,ground motion data have been extracted from PEER NGA database. Three ground motions i.e.,Gazli USSR,Imperial valley and Landers were selected with varying V/H ratio. Three-Dimensional orthogonal ground motions have been applied to all the bridge models for investigating structural response.

4. Result and Discussion

4.1 Pushover Analysis

Pushover analysis has been performed for evaluating the collapse load limit of each panel. Push load was applied at mid of top chord as shown in figure 4. Plastic hinges were assigned to all members at relative length of ten percentage. For bracing and beam members axial(P) hinges were assigned whereas for column member,parametric steel P-M2-M3 hinges have been assigned. Here methodology has been validated with the experiment performed by King and Duan in Experimental investigations of Bailey Bridges[5]. They have done experiment as well as analytical study and validated both result with each other. In that analysis small scale Bailey panel has been modeled with dimension of 20”x5”. Section size used was top and bottom chord as 19.4 mm x 19.4 mm and brace,column as 9.5 mm x 9.5 mm and collapse load was found to be around 40 kN.

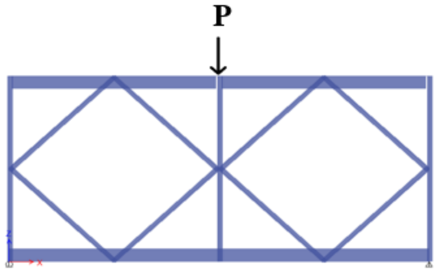

Figure 4: Application of push load

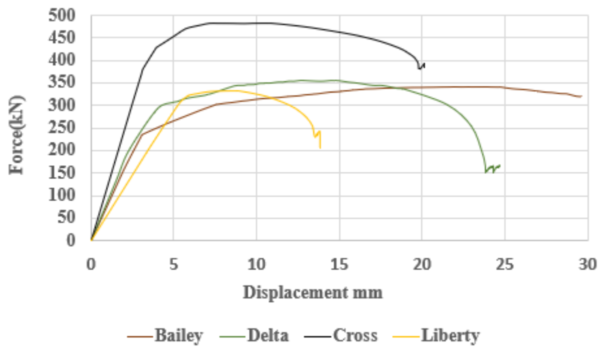

Figure 5: Pushover curves for different panels

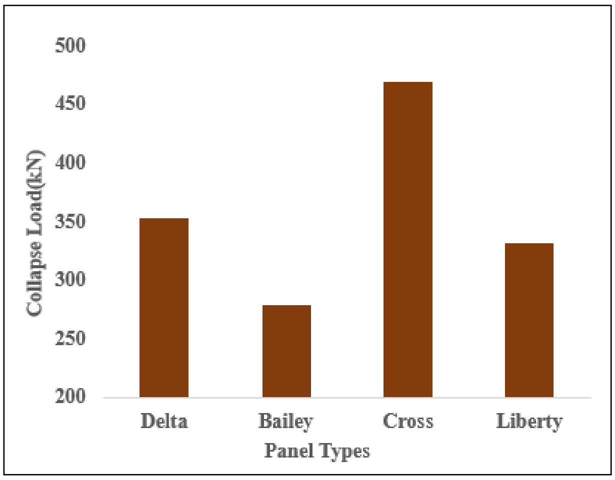

Figure 6: Collapse load capacity of different panels

Here, collapse load limit was determined which was found to be almost same as in their experiment and same process was carried out in order to determine collapse load capacity of real scale panels. Also,for the bridges with different panel arrangements,vertical push load has been applied at mid span of bridges in order to determine ultimate collapse load capacity of bridges.

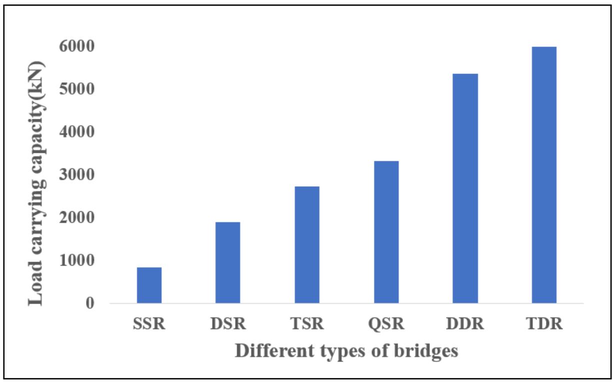

Figure 7: Ultimate load capacity of different Bridges

Here,in figure 5 we can see pushover curves for different types of panels. Several plastic hinges were formed at bracing ,column as well as in chords. According to formation of plastic hinges, structural deformation can be classified into life Immediate occupancy(IO),safety level(LS)and collapse prevention level(CP)[6]. Collapse limit load is taken such that push force corresponding to formation of collapse prevention level hinges. Collapse load capacity is maximum for cross panel and minimum for liberty panel. In liberty panel and delta panel, only one hinges formed at the end post but in cross panel it seems that several hinges formed at bracing which represent uniform load distribution over panel resulting more load carrying capacity.

From pushover analysis of panel bridges model for different panel arrangements, ultimate load carrying capacities of bridges model has been increasing on going from SSR to TDR gradually as shown in Figure 7. Even though both QSR and DDR uses same number of panels, capacity of DSR is almost 61 percentage greater. While stacking panels into vertical direction, collapse load seems to be amplified significantly due to increased stiffness as a result of enlarged moment of inertia in vertical direction.

4.2 Time History Analysis

Linear Time history analysis is performed in order to determine the structural demand on chord of panels as well as mid span deflection in real scale bridge models.

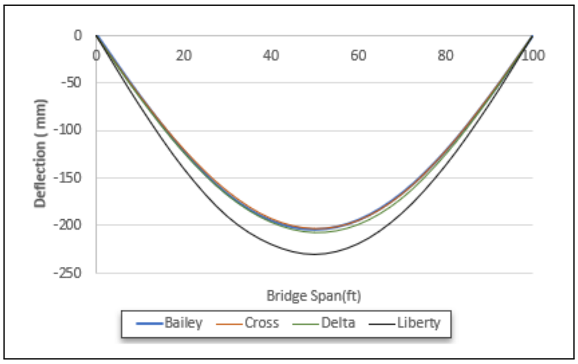

Figure 8: Mid-span deflection in different panel Bridge

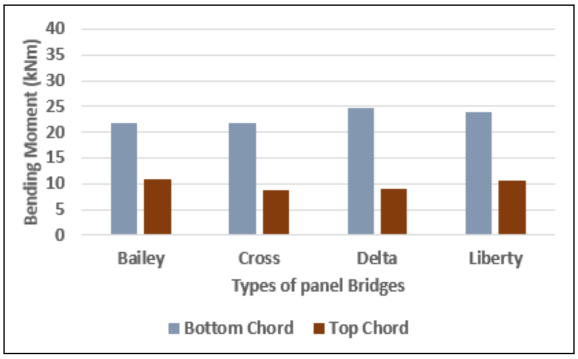

Figure 9: Bending moment in chord of panel Bridge

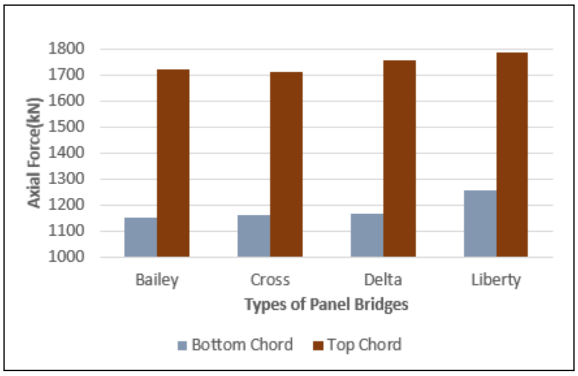

Figure 10: Axial force in chord of panel Bridge

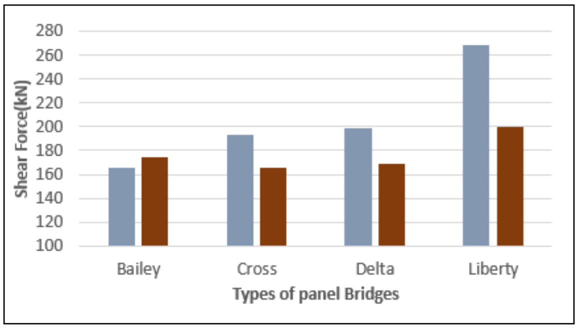

Figure 11: Shear Force in chord of panel Bridge

From the above plot of span vs mid-span deflection, mid span deflection for Bailey panel and cross panel bridge seems to be almost equal whereas mid-span deflection for liberty panel bridge is almost 13 percentage more than that of Bailey and Cross panel bridge and 11 percent more than that of delta panel bridge. Also, Axial force,Bending moment as well as shear force for Bailey and cross panel bridge is minimum for both top and bottom chord. Structural response demand is lesser in Bailey and Cross panel, it may be due to symmetric panel shape. Here,in figure 9,axial force is greater for top chord and way more less for bottom chord. It is due to that axial force in bottom chord is triggered only by excitation but in case of top chord,it is due to excitation plus in-plane and out-plane instability[7].

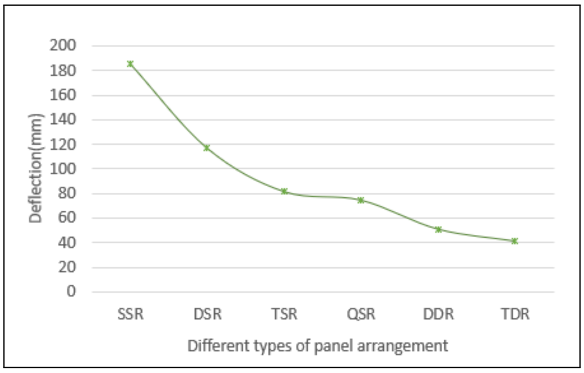

Figure 12: Mid-span deflection in panel Bridge

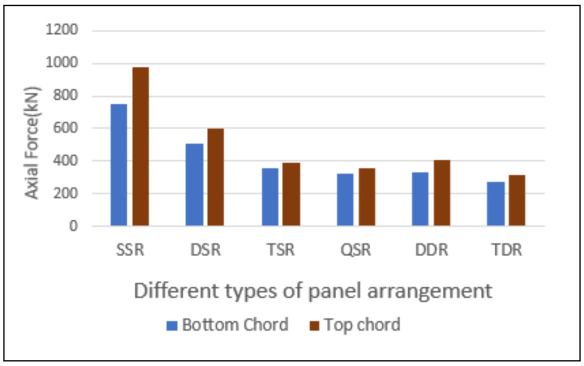

Figure 13: Axial Force in chord of panel Bridge

Here, we can see that on stacking number of panels in horizontal direction, mid-span deflection decreases gradually, but stacking panels in vertical directions results in decreased deflection by almost Thirty-one percentage on same number of panels. Also while going from SSR to TDR axial forces in the chord gradually decreases. while going from single to multi-storey, in-plane and out-plane instabilities increases which results in slight increment of axial force.

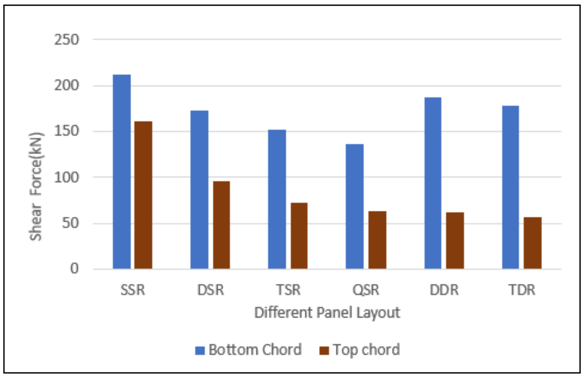

Figure 14: Shear Force in chord of panel Bridge

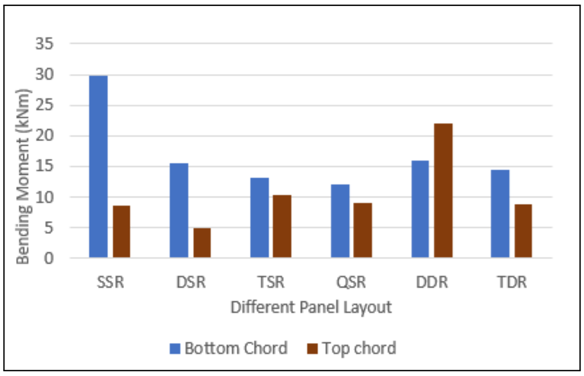

Figure 15: Bending moment in chord of panel Bridge

Also, bending moment and shear force tends to be in decreased manner while stacking panels horizontally from SSR to QSR but slight increment can be seen while stacking in vertical direction although same number of panels are used which may be due to second order effects.

The effect of vertical acceleration in the modeled panel Bridges can be studied on the axial force demand on the chord of panel. The contribution of vertical ground motion on the axial force variation on the chord normalized against dead load can be defined by

$$CVA = \frac{AVF(H+VGM) - AVF(HGM)}{DL} * 100 \quad (1)$$

Where,

- CVA=Contribution of vertical ground motion on axial force variation(Percentage)
- AVF=Axial force variation on the chord
- DL=Dead load of chord

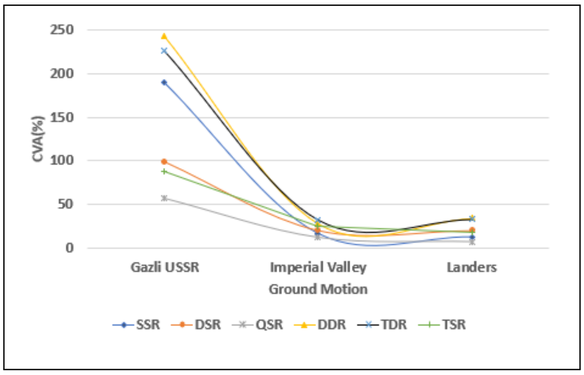

Figure 16: CVA in bottom chord of panel Bridge

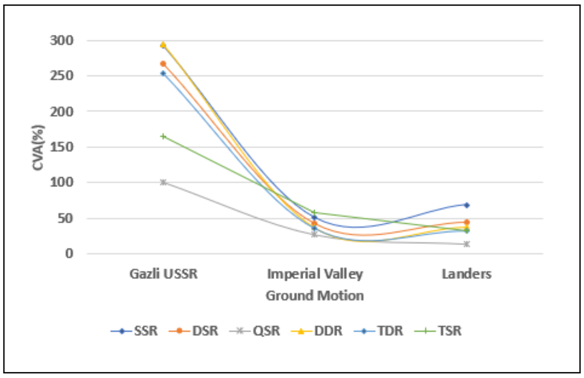

Figure 17: CVA in top chord of panel Bridge

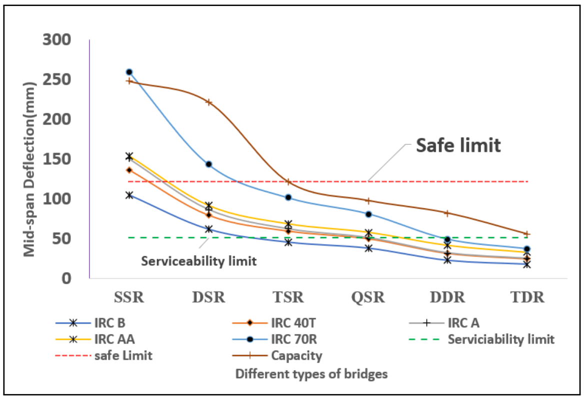

Figure 18: Mid-span deflection for different vehicle load for different bridges

Here,value of CVA ranges from 12 percent (landers) to 189 percent (Gazli USSR) in the bottom chord whereas 50 percent (Imperial valley) to 291 percent (Gazli USSR) indicating significant effect of the vertical ground motion on axial force level in SSR and 19 to 99 percent in DSR,17 to 88 percent in TSR,7 to 57 percent in QSR,27 to 243 percent in DDR and 31 to 226 percent in TDR of bottom chord. For top chord,CVA values are maximum for DDR and least for QSR. From here we can assume that effect of vertical ground motion in contrast with horizontal ground motion,it decreases gradually while stacking panels in horizontal direction whereas it slightly increases while stacking panels into vertical direction. Also,for some configurations,CVA values are greater even for smaller ratio of vertical to horizontal ground motion. From this we can say that earthquake records with higher V/H peak ground acceleration ratio don't necessarily induce maximum response.

From figure 18, deflection capacities for all types of bridge models were greater than the deflection demand from different vehicle loadings except for SSR in IRC 70R, which clearly reveals that all the models except SSR are safe against collapse for respective loadings. But,considering safe deflection limit (span/250),TSR,QSR,DDR and TDR are safe against loadings up to IRC class 70R where as DSR is safe for IRC class AA wheeled vehicle and SSR is safe upto IRC class B loading. Again if we take serviciability limit conditions,SSR and DSR induces more mid-span deflection which will be practically unserviciable in daily use. Also,QSR satisfies serviciablity limit upto IRC class A loading whereas DDR and TDR satisfies for all the vehicle loading considered here.

5. Conclusions

In this work,structural responses of panel bridges on dynamic loading has been studied out varying member configuration on panel and panel arrangements. After the analysis of all, the model data were collected. From the observation, following conclusion can be drawn out.

- Cross panel has 32 percentage, 68 percentage and 41 percentage greater collapse load capacity than Delta panel,Bailey panel and Liberty panel respectively as well as cross panel bridges induces lesser structural demand than other panel bridges.
- Axial forces in bottom chord is always lesser than in top chord of panel bridges whereas shear force and bending moment is always greater for bottom chord.
- Stacking Panels in vertical direction decreases mid span deflection by almost 31 percentage than stacking in horizontal direction.

- Ultimate capacity of bridges is in increasing trend from SSR to TDR however significant increase in capacity while moving from single storey to multi storey although number of panels are constant.
- Bending moment and shear force are always greater for multistoried panel arrangement than single storied panel bridges if same number of panels are used.
- Inclusion of Vertical component of ground motion has negligible effect in variation mid-span displacement whereas remarkable effect in axial force variation in the chord of panels.

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