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Vehicle Collision Impact Analysis of RC and HC-FCS Type Metro Rail Bridge Piers

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***Abstract*—Vehicles collisions on bridge piers are becoming a frequent issue due to overcrowding of vehicles in city roads, encroached spaces and lack of recommended margin around bridge piers etc. The safety of bridge structures, traffic systems and human lives etc are dramatically affected by such collisions and can cause damage to the support piers and exposed the whole structure to catastrophic failure. Therefore, scientific research is essential in this field due to severe bridge damages. In the present study, a Hollow-Core FRP-Concrete-Steel (HC-FCS) columns in which concrete wall sandwiched between an outer FRP tube and an inner steel tube is adopted as a possible structure for bridge pier. The dynamic behavior of the reinforced concrete (RC) bridge pier is to be compared with the dynamic behavior of the same pier with a jersey barrier and also with the behavior of an HC-FCS type pier during vehicle collision. A medium weight BharatBenz 2523R 6x2 truck model of 25ton is collided with the pier at a velocity of 90kmph. Finite element simulation ANSYS Autodyn is used for the study.**

Keywords— Impact; bridge piers; vehicle collision; metro system;RC column; HC-FCS column.

INTRODUCTION

With the development of transportation modes and facilities, the number of elevated bridge structures also increased. The high speed elevated metro rail bridges usually steps across the roadways and therefore the bridge piers are more exposed to vehicle collisions. The term collision can be related to the conventional law of conservation of momentum (Gomez 2014 [9]) which involves the collision of two bodies of different masses and different velocities. Many accidental heavy vehicles collisions with bridge piers have noticed in the past. Some of them had lead to many catastrophic consequences and may sometimes result in serious risks like failure of the bridge system and even loss of many human lives. Avinash S Joshi et al. (2012) [6] conducted a study in quantifying or estimating the vehicle collision damages in bridge piers.

A detailed study of vehicle collision impact on concrete bridge piers was conducted using inelastic transient finite element simulation by El-Tawil et al. (2005) [3] using two different type of trucks and two different bridges or pier system with two different approaching speed. Eugene Buth et al. (2010) [5] gathered the information regarding the effect of vehicle speed, weight, and bridge pier during vehicular collisions by experimentally investigating collisions of large tractor-trailer with the bridge piers. Tesfaye et al. (2013) [7] contribute to the characterization of pre- and post-peak behavior of concrete material with the evaluation of a damage scale analytical model using LS_DYNA software. Yazan Qasrawi et al. (2015) [15] predict the impact and blast response of regular round reinforced concrete column and concrete filled fiber reinforced polymer tubes (CFFTs) using ANSYS Autodyn software. The effect of diameter, size, reinforcement ratio etc is studied through different parametric studies.

Teng et al. (2004) [2] modified an innovative steel-concrete-steel double-skin tubular column developed by Montague in1978 with an outer FRP (Fiber Reinforced Polymer) tube and inner steel tube and its behavior is studied in detail. Azadeh et al. (2014) [12] explained the progress in strengthening of concrete columns using fiber reinforced polymers. Omar I. Abdelkarim et al. (2014) [13, 14] experimentally tested and investigated numerically the behavior of the HC-FCS (hollow-core FRP -concrete-steel) columns under combined axial and lateral loading through parametric studies. Its compressive behavior is also studied. Omar I. Abdelkarim et al. (2015) [16, 17] explains behavior of hollow-core FRP -concrete-steel columns during vehicle collisions by comparing the dynamic behavior of both Reinforced Concrete (RC) and HC-FCS columns using LS_DYNA software and also its behavior under extreme loadings.

HC-FCS PIERS

In HC-FCS columns the concrete wall is sandwiched between an outer FRP tube and an inner steel tube. It is a modified form of double skin tubular column which combines the benefits of both concrete-filled tube columns and hollow-core concrete columns. The benefits of FRP, concrete, and steel were combined and optimized together. The steel tube act as flexural and shear reinforcement whereas FRP tube confines the sandwiched concrete. HC-FCS column are mainly used for tall bridge piers in moderate to high seismic regions. The HC-FCS column has several advantages over reinforced concrete (RC) columns. It reduces the amount of concrete material by 60 to 75%, since it has hollow-core (Fig. 1).

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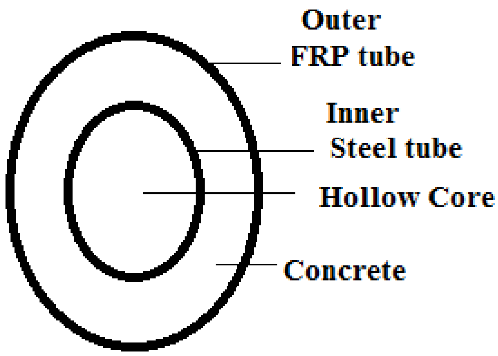

Fig. 1: HC-FCS pier cross section view

HC-FCS columns reduce the overall mass of the column, which reduces the contribution to the inertial force by bridge self-weight during an earthquake. The FRP tube protects the concrete from spalling. The inner steel and outer FRP tubes provide a high confinement and ductility to the concrete shell; hence, the concrete shell shows significantly higher strength, ductility and strain when compared to unconfined concrete. An efficient use of the steel tube is achieved since the concrete shell can reduce the local buckling of the steel tube. The HC-FCS columns are highly corrosion resistant since the steel tube is well protected by the outer FRP tube and concrete core which are corrosion-free.

A metro system is an electric passenger railway transport system usually elevated with high capacity, frequency and grade separation from other traffic with tall piers open to lateral vehicular impact. Kunpeng Cui et.al (2014) [11] studied the force characteristics analysis of a railway pier during vehicle collision through parametric studies using finite element software LS_DYNA.

VALIDATION

Experiments of vehicular collision on bridge piers are difficult and expensive. Therefore the impact model used by Yazan Qasrawi (2015) [15] using ANSYS Autodyn was used for the validation purpose. The first specimen of 4m length and 209mm diameter with four 10M longitudinal bars having tensile yield strength of 430MPa, ultimate strength of 577MPa and young's modulus of 170GPa is taken (Fig. 2). The specimen has a continuous steel spiral shear reinforcement of 6mm with a spacing of 0.1m. At the ends within 0.2m the spacing is 0.05m and has a tensile yield strength of 645MPa, ultimate strength of 713MPa and young's modulus of 194GPa. The concrete used has a compressive strength of 34MPa. The impact hammer used is standard 4340 steel with a density of 10g.cm^{-3} and a weight of 561kg. The velocity in y direction is taken as 1.56ms^{-1} downwards. In Autodyn results at predetermined locations are chosen by the user by setting gauge points. Gauges are placed at midspan, each of the extreme ends etc.

The experimental value obtained in paper Yazan Qasrawi (2015) [15] is 0.094m and the numerical value obtained as per this study is 0.102m (Fig. 3). Therefore the percentage of difference is 8.5%.

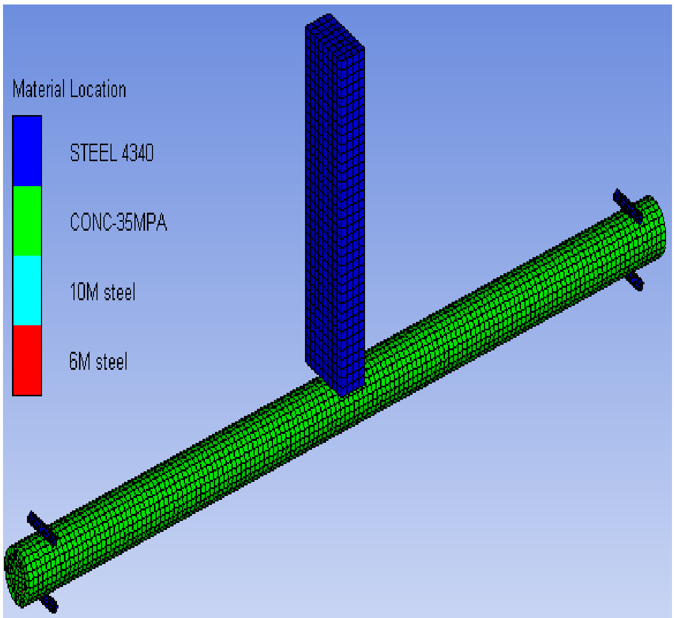

Fig. 2: Validation beam model for hammer impact test

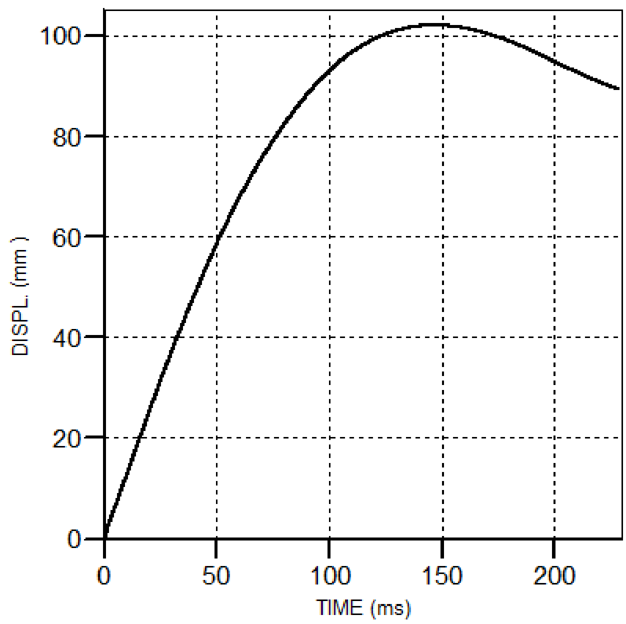

Fig. 3: The displacement time plot

FE MODELING

The FE modeling is conducted on ANSYS Autodyn. The RC bridge pier taken for this study is the bridge pier of Kochi metro rail which is an under-construction metro rail system for the city of Kochi in Kerala, India. The 25.65km metro line with 22 stations will run from Aluva to Petta. A single pier supporting the viaduct located on the median of road generally spaced at 25-m centers and with a diameter of 1600mm is taken for the study. A Jersey Shaped barrier of 1.0m height and 200mm thickness has been provided all around the pier above existing road level. The increase in impact resistance with the use of Jersey barrier is numerically analyzed and also the change in impact resistance if an HC-FCS type pier is used for this metro system instead is analyzed.

GEOMETRY AND LOADING

Each pier has an outer diameter of 1.6m and the height of the pier including the portion inside the pier cap is 10m. The HC-FCS piers are designed to have the same flexural strength, diameter and height as that of RC piers. The longitudinal steel reinforcement of the RC column was 40 numbers of 25mm Ø bars and 12 numbers of 32mm Ø bars with 75mm cover. A Jersey Shaped barrier of 1.0m height 0.2m thickness has been provided around the pier with a gap of 0.025m and reinforcement of 10mm Ø bars at 125mm c/c in the second model. The outer FRP tube thickness of the HC-FCS column was 8.0mm. The outer diameter of the inner steel tube (Di) was 1.0m and its thickness was 10mm (Omar I. Abdelkarim 2015 [17]). The diameter-to-thickness of the steel tube was 100 > 64. The inner steel tube was extended inside the footing and pier cap using an embedded length (Le = 1.5 Di), while the FRP tube stopped just below the pier cap and at the top of the footing. The steel tube was hollow inside. The HC-FCS column did not contain any flexure or shear reinforcement except the steel tube.

In these models, the bridge piers are supported on reinforced concrete pile cap of size 4400 x 4400 x 1500mm which is supported on four piles of 1000mm diameter which has fixed boundary condition at its bottom. The upper boundary condition is pinned. The axial load on the bridge pier is to be considered during analysis. The different loads to be considered include the self weight of 'U' girder, pier cap, track rail, track slab etc. Therefore, total axial load on pier is taken as 4364kN.

The concrete used is M50 concrete with RHT concrete properties with 50MPa compressive strength. The tensile failure stress is 5000kPa and the geometric strain erosion is 0.0035. The steel material used for HC-FCS is as per Omar I. Abdelkarim (2015) [16] with elastic modulus of 200GPa, yield stress of 420MPa and Poisson's ratio of 0.30(Caltrans 2006). The CFRP material with elastic modulus of 70GPa, shear modulus of 3GPa, and poison's ratio of 0.05 is taken for this study. Autodyn will save only the results at the predetermined locations. Therefore gauge points are to be set in-order to get the complete results. Here gauge points are set on the extreme collision end of the piers.

All the pier models were collided with a vehicle model of BharatBenz 2523R (6x2) (Fig. 4). The truck model taken is a medium weight truck with a gross vehicular weight of 25tons with a maximum velocity of 90km/hr.

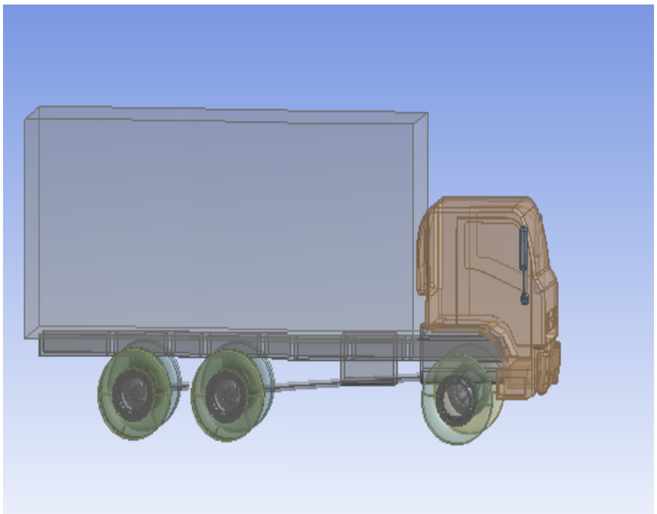

Fig. 4: FE vehicle model

RESULTS AND DISCUSSIONS

The deflection occurred in each pier type is collected and compared. The RC pier without any barrier is compared with the RC pier with a jersey barrier and with the HC-FCS type pier (Fig. 5, 6, 7). The RC pier with a jersey barrier deflect 70 to 75% less than that of RC pier without any barrier whereas the HC-FCS pier deflect 55 to 60% less than that of RC pier without any crash barrier or protection when it is collided with a 25ton truck at a velocity of 90kmph. Even though the barrier crashed, RC piers protected with the Jersey barrier shows 10 to 15% more impact resistance than HC-FCS type bridge piers. The displacement graph is shown in Fig. 8, 9 and 10.

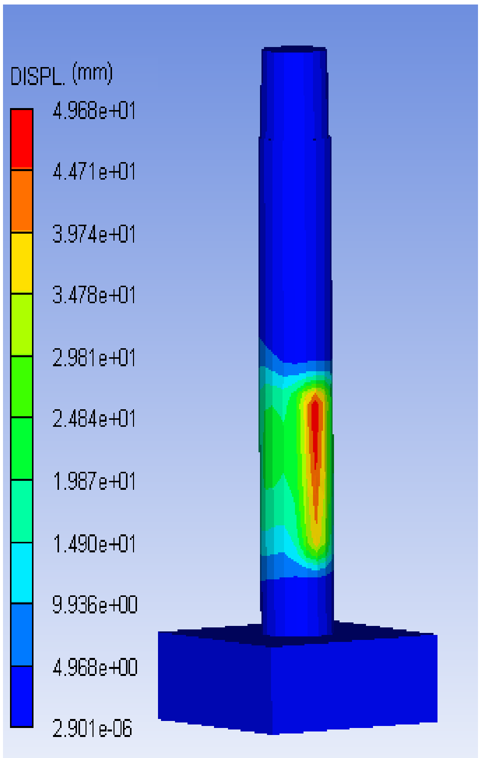

Fig. 5: Displacement in RC pier without any barrier

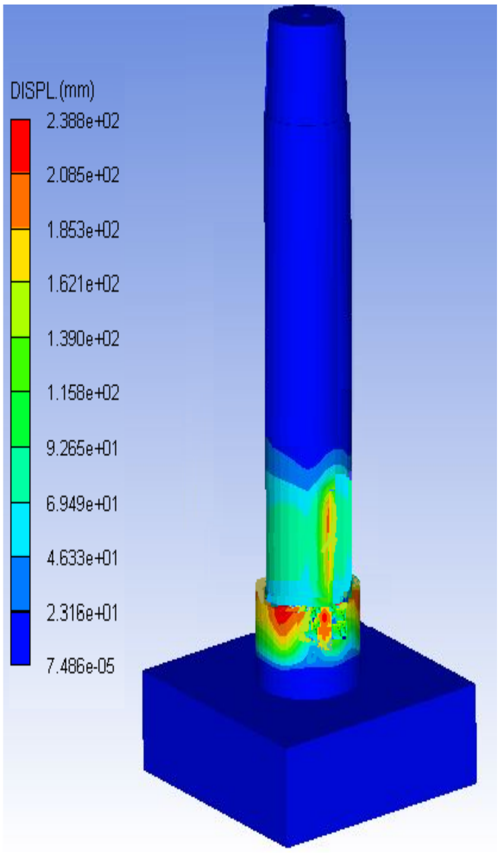

Fig. 6: Displacement in RC pier with a jersey barrier

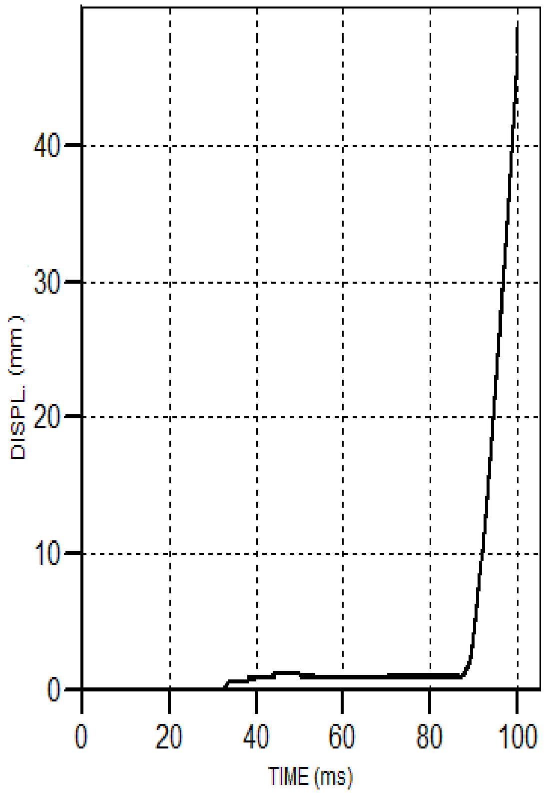

Fig. 8: Displacement graph of RC pier with barrier

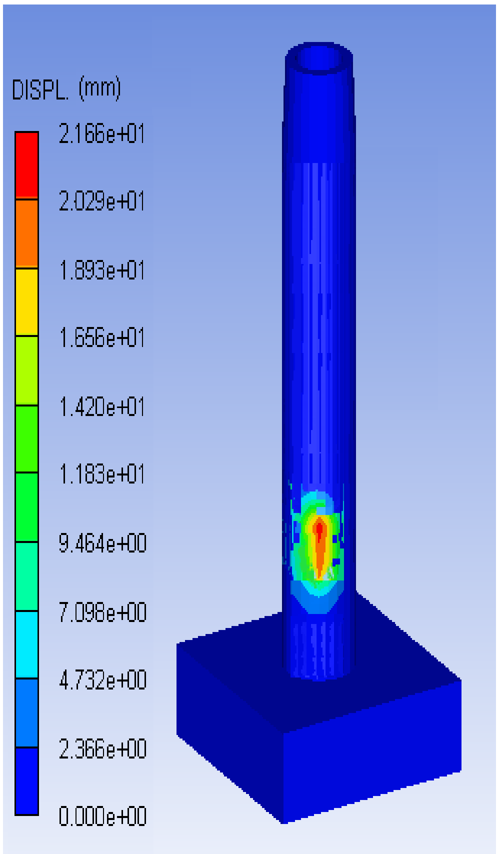

Fig. 7: Displacement in HC-FCS pier

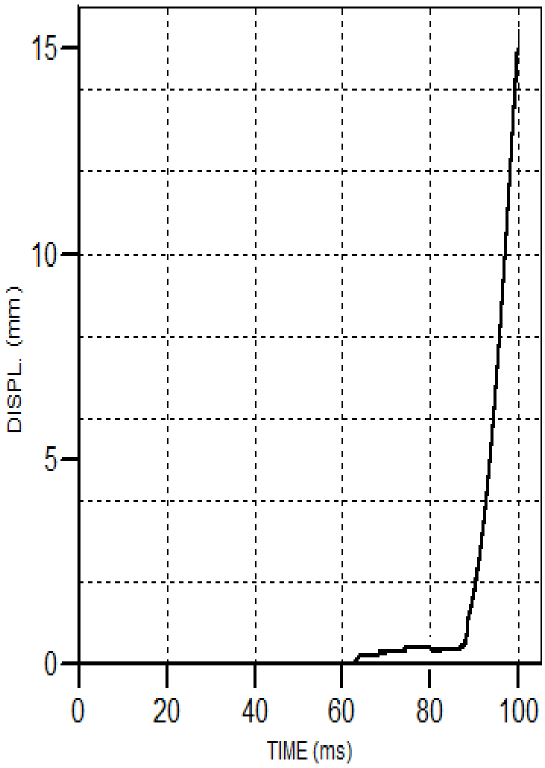

Fig. 9: Displacement graph of RC pier without any barrier

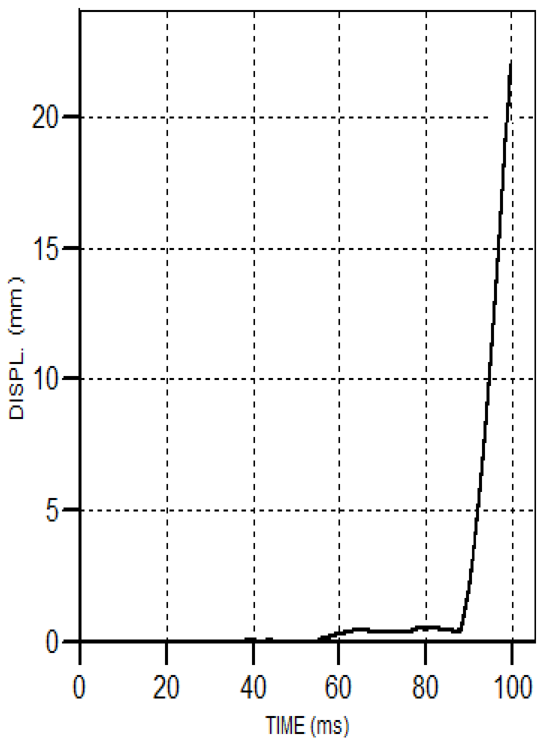

Fig. 10: Displacement graph of HC-FCS pier

CONCLUSION

Bridge piers are vulnerable to vehicle collisions and are faced with serious risks due to collisions. An efficient, quantitative, qualitative and reliable structure can be provided by properly analyzing its failure mode, deflection and impact force of the structure is necessary. RC piers are more affected by the collision impact force than strengthened columns, double skin tubular type columns etc. HC-FCS piers are a better possible pier type with several distinct advantages over reinforced concrete piers. It provides continuous confinement for the concrete shell and shows significantly higher strength, ductility and strain when compared to unconfined concrete. Even though RC piers with a jersey barrier shows 10 to 15% more impact resistance than HC-FCS type bridge piers, HC-FCS piers provide more seismic resistance spalling protection, more confinement, 60 to 70% reduction in concrete material etc. Hence HC-FCS is considered to have better performance than RC piers and need more studies based on.

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