IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 5 Issue 4, April 2018
ISSN (Online) 2348 – 7968
www.ijiset.com

Dynamic Analysis of Metro Rail Supporting Structure

Reshma Babu[1] and Jobil Varghese[2]

[1]Civil Engineering Department, APJ Abdul Kalam Technological University, Mar Baselios Institute of Technology and Science
Nellimatam, Ernakulam, India

[2] Civil Engineering Department, APJ Abdul Kalam Technological University, Mar Baselios Institute of Technology and Science
Nellimatam, Ernakulam, India

Abstract

The accidental loads due to impact, earth quake or blast may exceed the design load for which the structure is designed in exceptional cases. In the present day scenario, with increased vulnerability of structures to such loads, requires some measures to improve the resistance of the structures. This study presents a numerical study of the response of metro rail supporting structure that is the metro pillars under lateral impact load, seismic load and blast load using, finite element techniques and recommend some retrofitting methods based on a comparative analysis of FRP rib and concrete rib to overcome the adverse effect of impact loads. FRP rib is quite effective, so it can be preferred as a retrofitting method for columns. Also analyse the structure with damper to retrofit the pillar subjected to seismic loads. Also compared the results of impact loading obtained from static structural and explicit dynamics. The effects of various load parameters on the metro rail supporting structure were analysed in ANSYS 16.0.

Keywords: *Metro pier, crash barrier, Impact, seismic loading, Blast loading, FRP rib, Damper.*

2. Introduction

1.1 General

India is created a world-class Metro Rail Transit System (MRTS) as an integral part of community infrastructure development in the country. It is a cheap mode of transport, MRTS helps in low energy consumption, is eco-friendly, runs on electricity thus minimising the air and sound pollution and reduces the number of accidents. There are metro systems in the following busiest cities in India they are Delhi, Mumbai, Chennai, Bengaluru, Hyderabad, Jaipur and Kochi.

Kochi Metro is a newly constructed metro system for the south Indian city of Kochi in Kerala, India and is the fastest metro project in India in terms of completion time. Former Prime Minister Dr.Manmohan Singh laid the foundation stone for the Kochi Metro rail project in 2012. Kochi metro have an elevated viaduct carried over pre-stressed concrete 'U' shaped girders with pile foundations. Modern rolling stock of 2.9 m wide and having an axle load of 15 tonnes is rolling over the metro. The 'U-shaped' girder was cast at the Metro Casting Yard at Kalamassery. Fig. 1 shows the circular pillars. The pillars of 1.6 m diameter need to be located in the median of NH for Metro viaduct and span of each girder is 25m.

Fig. 1 Kochi Metro Pillars

1.2 Accidental Loads

Accidental Loads are loads which are imposed on the structure under abnormal and unplanned conditions. The overall goal for the design of the structure against accidental loads is to prevent the incident from developing a major accident. This means that the main safety functions should not be impaired by failure in the structure due to the design accidental loads. Because of the nature of accidental loads the design approach may be different from normal loads. In this study, the response of metro rail supporting pillar under impact load using vehicular impact, seismic load was analyzed.

ISSN (Online) 2348 – 7968
www.ijiset.com

1.3 Impact Load and its Effect

The general problem of impact is extremely complex. Impact load is a high force or shock applied over a short time period when two or more bodies collide. A common case of impact, vehicle collision with a traffic barrier involves large displacements, material non-linearity, elastic and plastic instability under high strain rates. Vehicle collision with bridges can have serious repercussions with regard to both human life and transportation systems. Fig.2 shows an impact load by a vehicle on a metro pillar.

Fig. 2 Vehicular Impact on Hyderabad Metro Pillar

1.4 Seismic Loading and its Effect

When earthquakes occur, a structure undergoes dynamic motion. This is because the structure is subjected to inertia forces that act in opposite direction to the acceleration of earthquake excitations. These inertia forces are called seismic loads. Since earthquake motions vary with time and inertia forces vary with time and direction, seismic loads are not constant in terms of time and space. Time histories of earthquake motions are also used to analyze high-rise buildings, and their elements and contents for seismic design. Earthquake or seismic analysis is a subset of structural analysis which involves the calculation of the response of a structure subjected to earthquake excitation.

1.5 Blast Loading and its Effect on Structures

Explosive is widely used for demolition purposes in: military applications, construction or development works, demolitions, etc. It is, also, a very common terrorist weapon as it is available, easy to produce, compact and with a great power to cause structural damage and injuries. The use of vehicle bombs to attack city centers has been a feature of campaigns by terrorist organizations around the world. Fig. 3 shows a bridge in Iraq severely damaged by a relatively small amount of explosive placed by terrorists near piers of the bridge. The analysis and design of structures subjected to blast loads require a detailed understanding of dynamic response of various structural elements.

Fig. 3 Bridge in Iraq Damaged by Terrorist Attack

3. Geometry of the Problem

The structure to be analysed was modelled in ANSYS Workbench 16.0. The metro consists of a pile cap, crash barrier, pier, pier head, a concrete support, elastomeric bearing and girders. The pier was anchored in the soil by means of pile foundation. The pile cap has a diameter of 3.6m. A small crash barrier is provided with a diameter of 2.5m having a height of 1.5m from pile cap to protect the piers from small vehicle impacts. The pier is circular in shape and has a diameter of 1.6 m. The pier has a height of 4.5 m to cater for the smooth movement of traffic underneath the metro. Concrete supports are provided over the pier cap to support the elastomeric bearings. Elastomeric bearing pads compress on vertical load and accommodate horizontal rotation and provide lateral shear movement. Above the elastomeric bearings two girders of length 25m are spanning in either directions. Only circular piers having a diameter of 1.6 m is considered in the thesis. The Front view of pier from ANSYS is shown in Fig. 4.

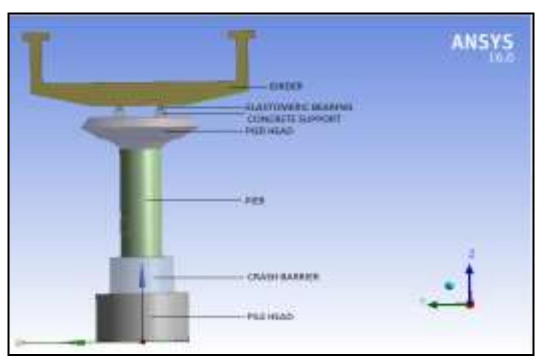


Fig. 4 Front View of Pier from ANSYS

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 5 Issue 4, April 2018
ISSN (Online) 2348 – 7968
www.ijiset.com

3.2 Modelling of the Problem

The physical problem was modelled as per the layout. For different types of analysis, it was required to input physical properties of the material and assigning the properties to different elements. After assigning the property, provide proper connections between different elements. Then do the meshing of the whole structure. There are many methods for meshing. After creating mesh, input necessary data such as support condition, load, in this study loads may vary like impact loading, seismic loading, blast loading etc.

3.3 Material Properties

The properties of the reinforced concrete were applied to the pile cap, crash barrier, pier, pier head and girders. M40 grade concrete is given to pile cap and crash barrier since it is specified in code IRC: 6, that is minimum grade of concrete for crash barrier is M40. M35 concrete is provided for pier, pier head and girders. For the bearings, property of elastomer is given. The different properties given to various elements are given below in Table No.1.

Table No. 1 Material Properties

	A	B	C
1	Property	Value	Unit
2	Density	2540	kg m^-3
3	Isotropic Elasticity		
4	Derive from	Young's M...	
5	Young's Modulus	32000	MPa
6	Poisson's Ratio	0.2	
7	Bulk Modulus	1.7778E+10	Pa
8	Shear Modulus	1.3333E+10	Pa
9	Field Variables		
13	Bilinear Isotropic Hardening		
14	Yield Strength	355	MPa
15	Tangent Modulus	0	Pa
16	Tensile Yield Strength	4.42	MPa
17	Compressive Yield Strength	40	MPa

3.4 Connections, Meshing and Support Condition

After assigning properties to various elements, provide connections between areas having contacts. Bonded connections are provided between pile cap and crush barrier and also between pier and pier head. Frictional connections are provided between the contact area of elastomer and girder because of the different materials used for the construction. Frictional coefficients between elastomer and concrete are 0.1.

In Finite Element Analysis (FEA), meshing is an integral part of analysis for that, the model is divided into small discrete regions called finite elements. The meshed image of the structure is shown in Fig. 5. In the next step, the support conditions are assigned. Fixed supports are given below the columns. At the bottom of the pier, the rebars are extended into the crash barrier and pile caps and, the pile caps, crash barrier and the piers are cast monolithically.

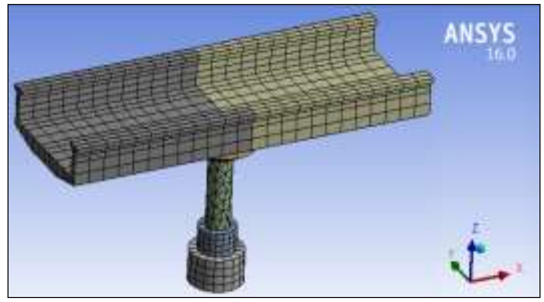
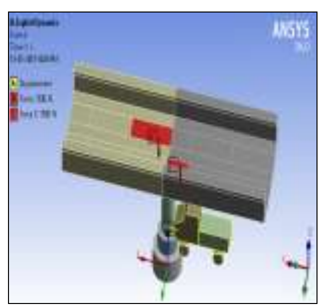


Fig. 5 Meshed Structure

4. Analysis and Results

4.1 Analysis of Combined Action of Moving and Impact Load in Explicit Dynamics

Analysis of on time action of moving load and vehicular impact load was done and in explicit dynamics. For the analysis in the explicit dynamic, it was required to draw a vehicle and mass and velocity (in m/s) of the vehicle was applied to vehicular body in kg. The load applied in explicit dynamics is shown in Fig. 6. For the moving load critical case is when the two trains are above the pillar. So vehicular impact is given at that time when the trains are approaching the pillar. After solving the structure, deflection of the metro pier was detected and it is shown in Fig. 7. Deformations generated in the various cases are found by changing mass and velocity of the vehicle. These results are tabulated and compared.



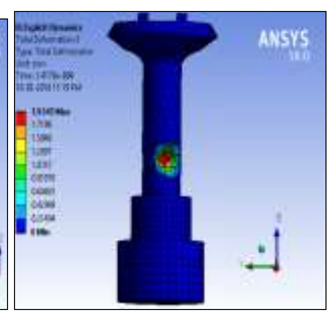


Fig. 6 Impact Load on Pier Fig. 7 Deformations on the Pier

4.1 Analysis of Combined Action of Moving and Impact Load in Transient Structural

In transient structural analysis instead of drawing vehicle and apply mass and velocity on the vehicle, it is necessary to calculate impact pressure and apply on the face where

ISSN (Online) 2348 – 7968
www.ijiset.com

impact happens. Loading on structure is shown in Fig. 8. In this study compared the deformation of the structure when impact given to crash barrier and on pier. Deformation of the structure when small vehicular impact occurs on crash barrier and pier is shown in Fig. 9. The equation for impact pressure is shown below,

$$Impact\ Force = \frac{2mv}{t} \quad (1)$$

Where m- Mass of vehicle in kg, v- Velocity of vehicle in m/s, t- Impact time = 0.05s

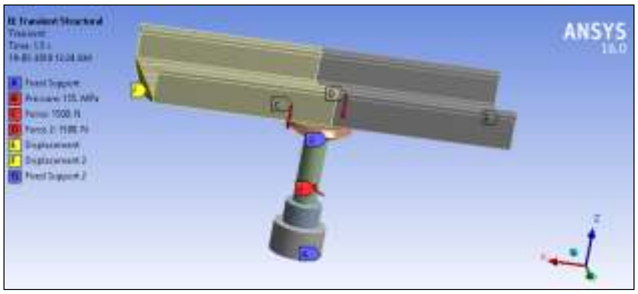


Fig. 8 Impact Pressure on Pier

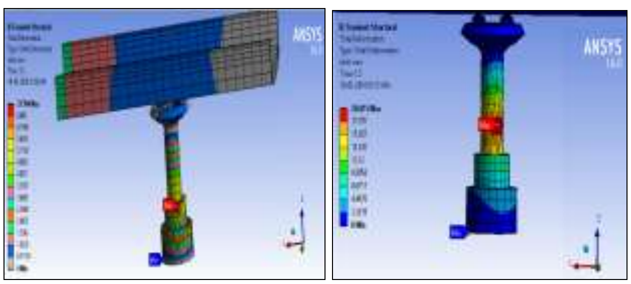


Fig. 9 Deformations on Crush Barrier and Pier

4.3 Analysis of Retrofitting Method Using GFRP Rib and Concrete Rib against Impact Loading

The possibilities of spalling after the impact loading make the system more vulnerable. In order to improve the performance of structures under impact loads, many structural forms are introduced and found to give satisfactory results. In this study, a comparison of deformation of the structure when concrete rib and FRP rib are provided. Deformation of the pier with concrete rib and FRP rib are given in Fig. 10.

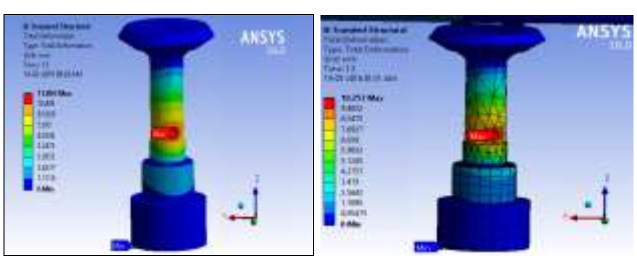


Fig. 10 Deformation of Pier with Concrete Rib

4.4 Analysis of the Structure under Seismic Loading

When earthquakes occur, a structure undergoes dynamic motion. Earthquake or seismic analysis is a subset of structural analysis which involves the calculation of the response of a structure subjected to earthquake excitation. For the seismic analysis past earth quakes response of a structure were referred. In this study, seismic data of El Centro Earthquake happened in 1940 were used. It had a moment magnitude of 6.9. The time-acceleration data of El Centro Earthquake is shown below in Fig. 11. The structure was analysed and resulting deformations were found out. The resulting deformations are shown in Fig. 12.

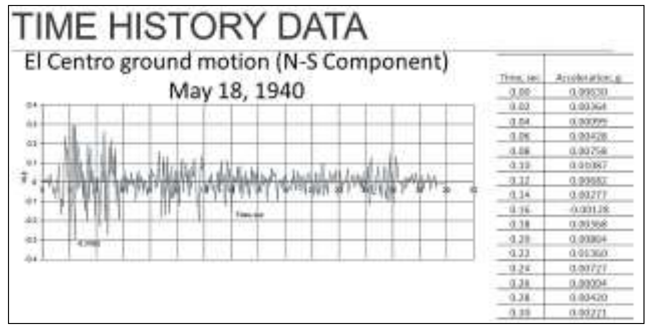


Fig. 11 Time – Acceleration Data of El Centro Earthquake

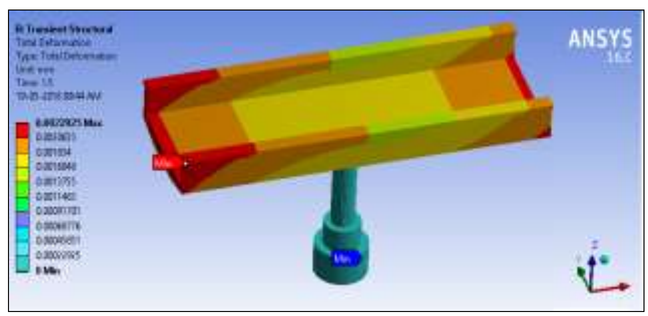


Fig. 12 Deformation of Pier Subjected to Seismic Loading

4.5 Analysis of Structure with Damper under Seismic Loading

The Kochi metro is situated in seismic zone III. Seismic retrofitting is the modification of existing structures to make them more resistant to seismic activity. A tuned mass damper is a device mounted in structures to reduce the amplitude of mechanical vibrations. In an earthquake, the damper can consume the vibration's energy and protect the main structure and components from damage to ensure its safety. The deformation of the structure with damper is shown in Fig. 13.

ISSN (Online) 2348 – 7968
www.ijiset.com

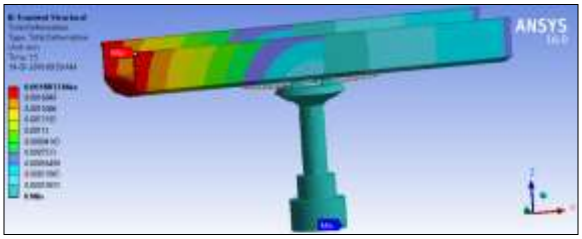


Fig. 13 Deformation of Pier with Damper Subjected to Seismic Loading

4.6 Analysis of Structure Subjected to Blast Loading

As there is an increase in population, there has also been an increase in accidents. Explosion loads are high pressure impulses acting over milliseconds. This report focuses on the investigation of behavior of the structure under blast loads. The effect of stand-off distance and weight of explosive on the structure were analysed. The blast pressures was calculated as per Brode's equation,

$$P_S = \frac{6.7}{Z^3} + 1 \qquad (2)$$

Where, P_S – Blast Pressure, R- Stand-off distance, W- charge

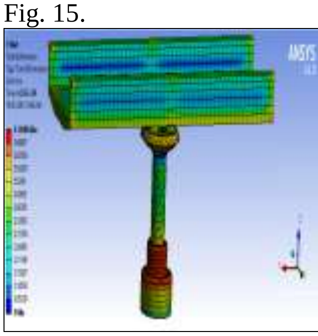
$$Z = \frac{R}{W^{\frac{1}{3}}} \qquad (3)$$

Table No. 2 shows the various stand-off distances, weight of explosive and corresponding deformation and stresses.

Table No. 2 Computation of Blast Pressures according to Brode's Theory

R(m)	W (kg)	P_S	Deformation (mm)	Stress (MPa)
5	250	14.5	0.74	43.4
5	700	38.5	2.3	55.3
5	1500	81.4	6.5	127.7
10	250	2.7	0.08	3.5
10	700	5.7	0.25	10.1
10	1500	11	0.53	30.1

The deformation is obtained when a stand-off distance of 5m under an explosive weight of 250kg of TNT is shown in Fig. 14. The stand- off distance of explosion is shown in Fig. 15.



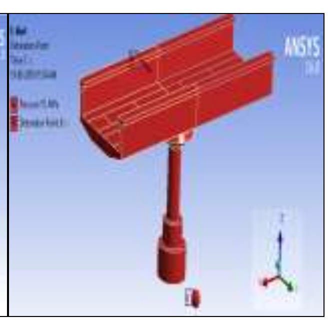
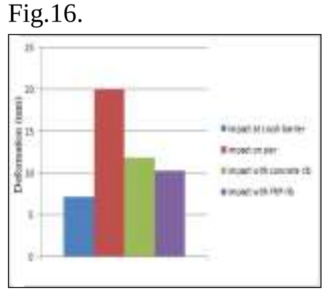


Fig. 14 Deformation of Pier   Fig: 15 Stand- off Distance

5. Discussions

Analysis was conducted using ANSYS Workbench 16.0 and deformations generated in various load cases were determined. In the case of impact loading, response of the structure was analysed in both Explicit Dynamics and Transient Structural. The resulting deformation is more in transient structural than explicit dynamics, because of impact area. As the impact area increases deformation decreases. In the first case, the analysis of impact load on crash barrier and pillar was done in Transient Structural. From Fig. 16, it can be inferred that impact on crash barrier cause minute deformation whereas impact on pillar cause more deflection. From Fig. 17 it can be concluded that increase in deformation of the pillar increases with increase in mass and speed of vehicle. The permissible deflection of a structure is 18mm, beyond that limit it is necessary to provide any additional structure. So a rib is provided at the bottom of pier and compared the results of both concrete rib and FRP rib. It is found that both FRP rib and concrete rib reduces the deformation to half and makes it within permissible limit, this can also be inferred from Fig.16.



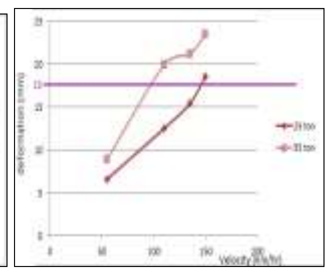


Fig. 16 Variation of Deformation   Deflection Vs Speed

The metro rail supporting structure subjected to seismic loading was analysed and resulting deformations was obtained. Deformations were obtained corresponding to previous earth quake acceleration - time history. To avoid the effect of seismic load on metro pier it is effective to provide a viscos damper on the structure. It is found that the deformation of the structure reduces when dampers are provided. From Fig. 18, it can be inferred that the structure with damper is safer in seismic zones. Because damper can consume the vibration's energy produced by the earth quake and protect the main structure and components from damage to ensure its safety.

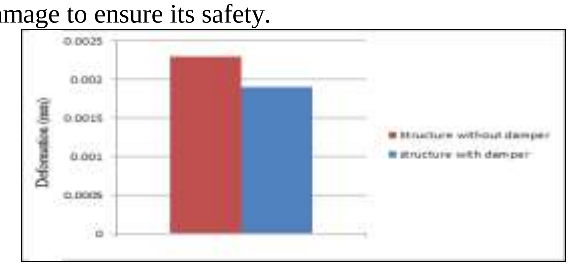


Fig. 18 Deformation of structure with and without Damper

ISSN (Online) 2348 – 7968
www.ijiset.com

In the modern metros, roads are running on either side of these pillars, as the metros are constructed at the center of roads. Any accident involving a blast can damage the pillar and resulting serious injuries and even loss of life. As the stand-off distance for explosion increases, the effect of blast on the structure decreases. Also if the explosive charge weight increases, it will increase the adverse effect of blasting. So designing the structure to be blast resistant can help in reducing the casualties to a great extent..

6. Conclusions

The increased vulnerability of structures to accidental loads demands the efforts to improve the resistance of a structures, for that it require some additional or alternate structural forms as a retrofitting methods to overcome the adverse effect. Metro rail supporting structure were analysed for various accidental load cases that may happen and different retrofitting methods were suggested. Metro pillar is safe to some extend against impact loading, and earthquake. But if a vehicle having weight and speed more than 30ton and 150km/hrs respectively in the case of impact loading the deformation will exceeds the permissible limit. As the impact area decreases deformation will also increases. If either the mass or the speed of the vehicle increases, there may be a chance of excess deformation. If an additional structure in the form of FRP rib is provided beneath the pillar, it will reduces the deformation to 50% in the case of vehicular impact. Considering the economical factor and cost of material it is found that FRP rib is more economical. It will be more effective to withstand the impact load. In the case of seismic load, if any strong earthquake occurs, it will cause more vibrations and provision of a damper will reduces the effect to some extent by absorbing the vibration and thereby reduces the deformation. As the stand-off distance increases, effect of blast will be reduces, for that barrier width can be increased therefore the distance at which a vehicle with explosive can be parked closest to the metro pillar will increases to avoid suspicion. To reduce the after effect of blast some alternate structural forms are necessary.

Acknowledgments

I express my deepest gratitude to Mr. Jobil Varghese, Asst. Professor, MBITS, Nellimattom, my esteemed guide and my cordial thanks for his warm encouragement, thoughtful guidance, insightful decision, critical comments and correction of the thesis. I also express my sincere thanks to all the faculty members and students of the Civil Engineering Department of Mar Baselios Institute of Technology and Science for their co-operation and support.

References

[1] Jun Li, Hong Hao, "*Numerical Study of Precast Segmental Column Under Blast Loads,*" Engineering Structures 134 (2017).

[2] Conrad Kyei, AbassBraimah "*Effects Of Transverse Reinforcement Spacing on The Response of Reinforced Concrete Columns Subjected To Blast Loading,*" Engineering Structures 142 (2017).

[3] Hongwei Wang, Chengqing Wu, Fangrui Zhang, Qin Fang "*Experimental Study of Large Sized Concrete Filled Steel Tube Columns Under Blast Load,*" Construction and Building Materials 134 (2017).

[4] Yufeng Shi, Mark G. Stewart "*Spatial Reliability Analysis of Explosive Blast Load Damage To Reinforced Concrete Columns,*" Structural Safety 53 (2015).

[5] Serdar Astarlioglu, Ted Krauthammer "*Behavior Of Reinforced Concrete Columns Under Combined Effects of Axial And Blast-Induced Transverse Loads,*" Engineering Structures (2013).

[6] T. Ngo, P. Mendis,"*Blast Loading And Blast Effects on Structures An Overview,*" Loading on Structures (2007).

[7] Omar I. Abdelkarim, ElGawady *"Performance of Bridge Piers Under Vehicle Collision,"* Engineering Structures 140 (2017).

[8] S.Aghdamy, D.P.Thambiratnam "*Computer Analysis of Impact Behaviour of Concrete Filled Steeltube Columns,"* Advances in Engineering Software 000 (2015).

[9] B. Ferrer, S. Ivorra "*Impact Load In Parking Steel Column: Code Review And Numerical Approach,"* COMPDYN 2009.

[10]Xihong Zhang, Hong Hao,"*Experimental investigation of the response of precast segmental columns subjected to impact loading,*" International Journal of Impact Engineering 95 (2016).

[11] Manal K. Zaki "*Investigation of FRP strengthened circular columns under biaxial bending,*" Engineering Structures 33 (2011).

[12] Donghui Cheng , Yanhong Yang "*Design method for concrete columns strengthened with prestressed CFRP sheets,*" Construction and Building Materials 151 (2017).

[13] AlirezaRahai, HamedAkbarpour "*Experimental investigation on rectangular RC columns strengthened with CFRP composites under axial load and biaxial bending,*" Composite Structures 108 (2014).

[14] Niloufar Moshiri, Ardalan Hosseini "*Strengthening of RC columns by longitudinal CFRP sheets: Effect of strengthening technique,"* Construction and Building Materials 79 (2015).

[15] M. Shahawy, A. Mirmiran "*Tests and modeling of carbon-wrapped concrete columns,*" Part B 31 (2000).