has two degree-of-freedoms: horizontal displacement of the story and the brace with damper relative to the ground. The mass, stiffness, and damping coefficient of each floor are kept constant in this study, and the associated values are adopted from literature (Kelly et al. 1987).

The fundamental time period (T_s) of the first mode of the building is 0.3 s. The assumed preliminary data required to analyze the effects of blast-induced ground motion is given in table 1

SOLUTION PROCEDURE

For obtaining the numerical solution, an appropriate non-linear solution technique can be adopted. Among the many methods, one of the most effective is the step-by-step direct integration method. This problem is solved by modification of a step-by-step linear acceleration method. For obtaining accuracy in the solution process, the selected time interval is subdivided, whenever a change in phase of motion is anticipated. These can be possible for single point sliding system. But for multi-point sliding system this will be very complex. In this solution process, the response is evaluated at successive increment (10^{-4}second) of time for computational convenience. The condition of dynamic equilibrium is established at the commencement of each interval.

The performance of the friction damper has been evaluated for the range of pre-tensioning forces from 14.45 kN to 205.29 kN for the example structure. It has seen that different performance indices are minimized for different pre-tensioning forces. The optimum structural performance of the example structure can be obtained for a pre-tensioning force of 100 kN. This indicates that the use of friction dampers with the pre-tensioning force of 100 kN will provide good performance for a wide range of expected ground motions. Hence a pretension force of 100 kN has been selected for the evaluation purpose.

The response of the example structure with viscoelastic damper has been investigated for target equivalent damping ratio of 30%, i.e., 5% structural damping and 25% supplemental damping. However, in the case of the viscous damper, the damper stiffness is considered to be negligible. The damping coefficient of the viscous damper is assumed to be a constant value of 4 kN.sec/m for calculation. The equivalent stiffness and damping coefficient of dampers is calculated for both the devices using the available expressions (Hanson et. al 2001).

PERFORMANCE INDICES

Three dimensionless performance indices have been considered to characterize the efficiency of dampers. All these indices are defined as the ratios between the peak values of a certain response quantity (displacements, acceleration, base shear) of the frame with dampers, and the peak value of the same responses of the free or braced frame structure without dampers. Consequently, these indices are dimensionless and always positive with their value range usually between zero and unity. Values close to zero indicate excellent performance of the dampers in reducing the response while higher values close to one indicate ineffectiveness of the dampers (Swain et al. 2015). All the performance indices have been normalized with respect to both the free frame and the braced frame structures. This enables assessment of response reduction and performance enhancement of the structures with dampers including the influence of stiffness of the bracing system. In the present formulation by considering stick or sliding frictional resistance (slip load) equals to zero, the response for free frame structure can be obtained. Similarly, the response of brace frame structure can be obtained by considering stick or sliding frictional resistance (slip load) as an infinite value.

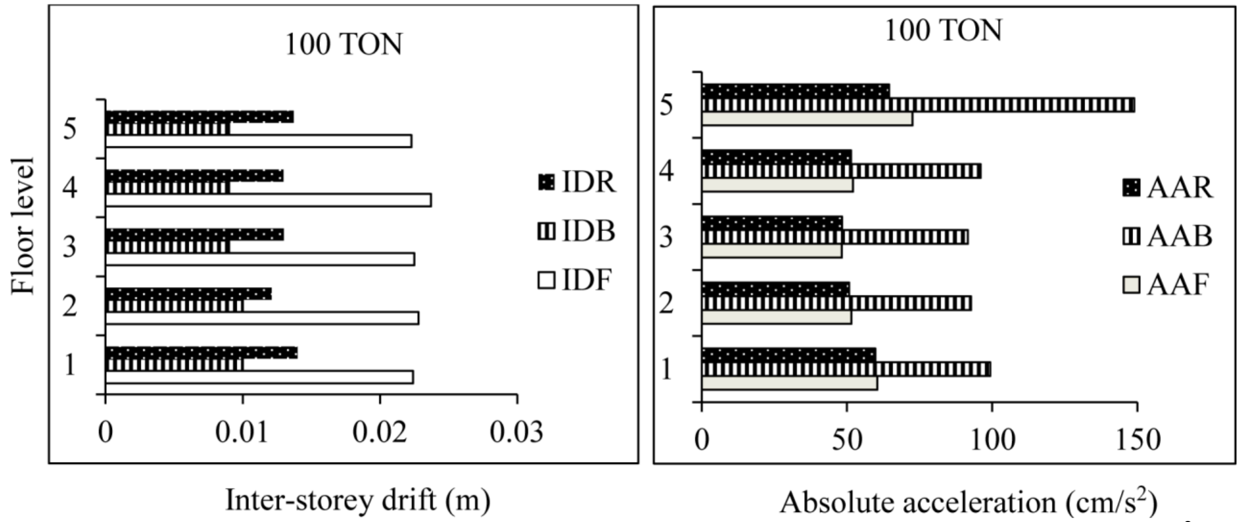

Figure 2. Maximum inter-story drift (m) and Maximum absolute acceleration (cm/s^2) response of the example structure floor wise with Friction damper subjected to 100 tons of blast-induced ground motion. (B - Braced frame, R - friction device and F - free frame)

BEHAVIOUR OF THE EXAMPLE STRUCTURE WITH DAMPERS

The maximum inter-story drift, floor displacement and the maximum absolute acceleration for the example structure are evaluated at each story level subjected to the ensemble of different blast-induced ground motions with various damping devices. Since the prime objective of the frame buildings with energy dissipation system is to reduce the peak responses, the investigations of maximum responses carried out to evaluate the effectiveness of the dampers.

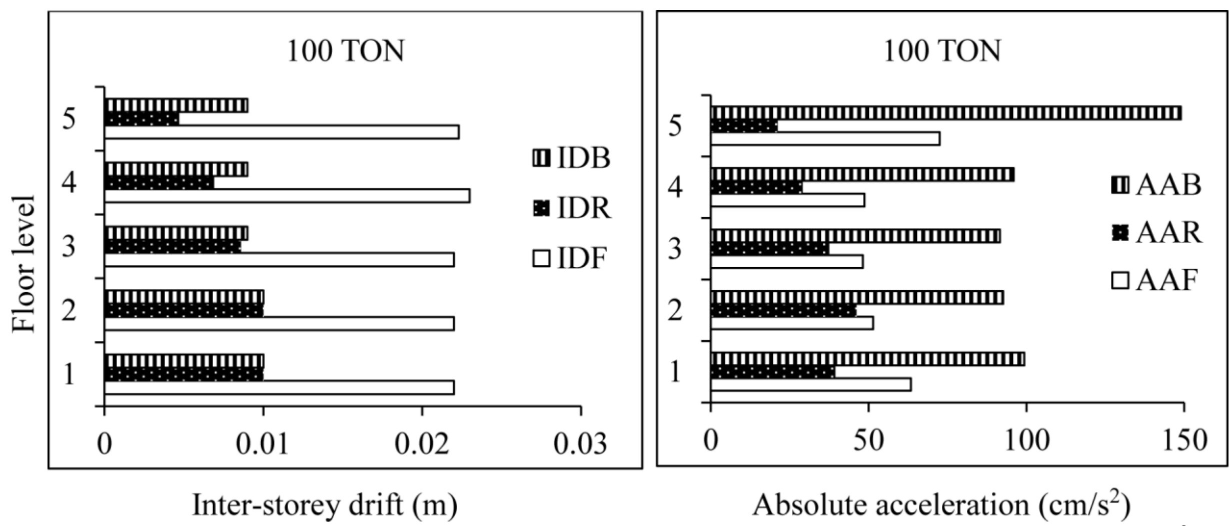

Figure 3. Maximum inter-story drift (m) and Maximum absolute acceleration (cm/s^2) response of the example structure floor wise with Visco-elastic damper subjected to 100 tons of blast-induced ground motion. (B - Braced frame, R – visco-elastic device and F - free frame)

Figure 2 shows that the inter-story drift of structure with friction damper can be reduced by overall 50% of the peak inter-story drift when compared to the free frame structure for 100-ton blast input data and no reduction in drift response occur when compared to the braced frame structure. In case of an absolute acceleration response of the structure reduced to a small percentage with friction damper in comparison of the free frame structure and 30% to 55% with reference to braced frame structure response. The reduction in the absolute acceleration response of a structure with friction damper in each storey in comparison to the free frame indicates small but the effectiveness of the damper in filtering the absolute acceleration of the system by reducing the kinetic energy into friction and heat in a lesser scale.

Figure 3 shows that the inter-story drift of structure with viscoelastic damper can be reduced by 50% to 70% from first to fourth storey and 80% in the top storey with respect to free frame structure response for case A type of blast-induced ground motion. However, when compared to the brace frame, it is seen that the inter-story drift has been reduced for all the floors except the first and second-floor level. This may be attributed to the high-frequency response of the viscoelastic model.

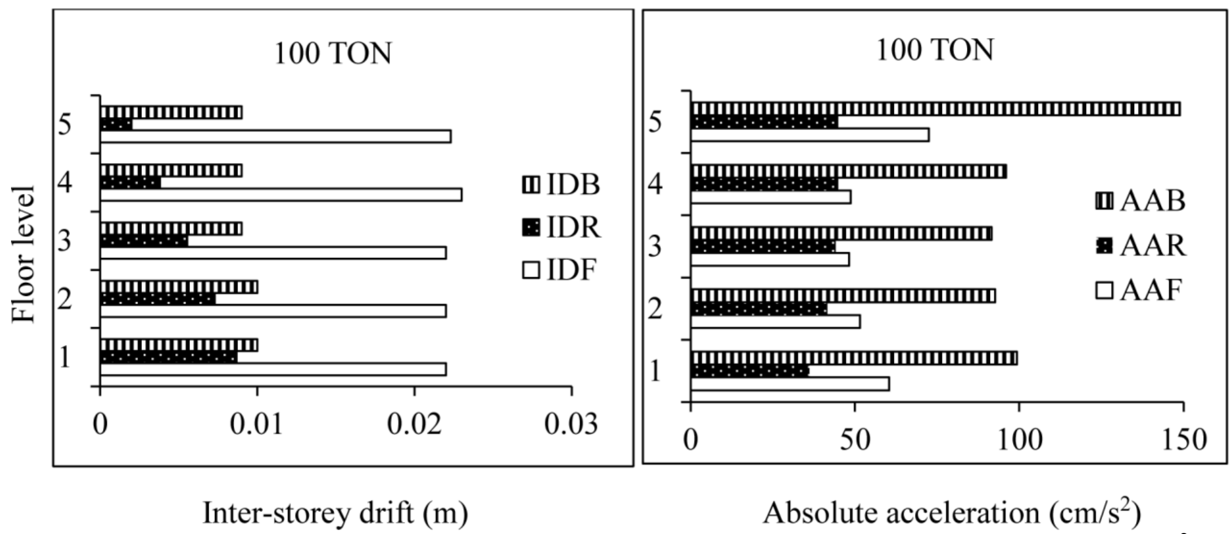

Figure 4. Maximum inter-story drift (m) and Maximum absolute acceleration (cm/s^2) response of the example structure floor wise with viscous damper subjected to 100 tons of blast-induced ground motion. (B - Braced frame, R – viscous device and F - free frame)

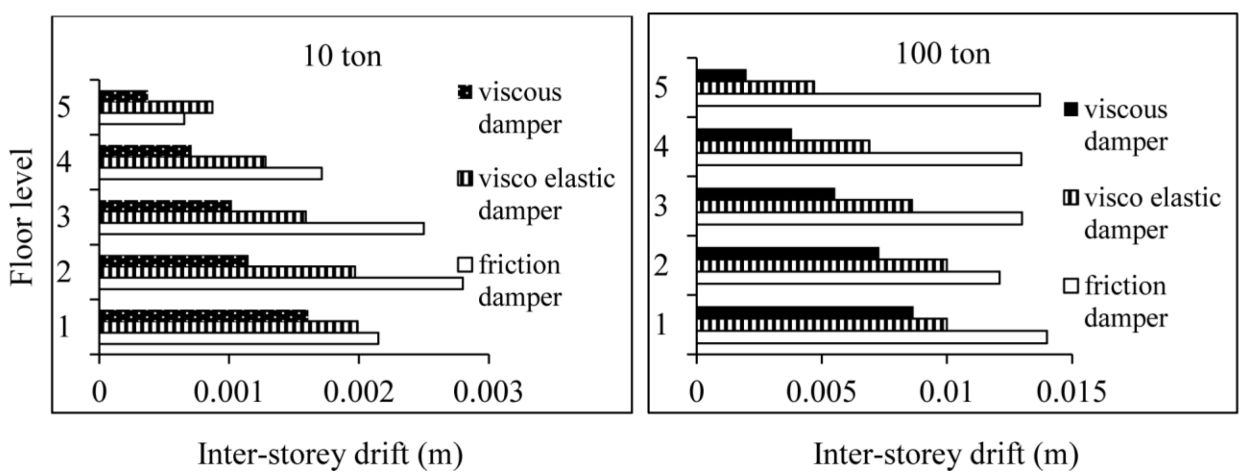

Figure 5. Maximum floor wise displacement response of the example structure with various dampers subjected to 10 tons and 100 ton of blast-induced ground motions

Figure 4 shows that the inter-story drift of structure with a viscous damper can be reduced by

55% to 85% with respect to free frame structure response for Case A types of BIGM. The interstory drift response reduction is in the range of 20% to 70% when compared with the braced frame. The maximum absolute acceleration of the structure with viscous damper can be reduced by over 20% to 35% of the absolute peak acceleration of free frame structure, and when compared with braced frame response overall 65% reduction was observed

In figure 5, a comparison of maximum inter-storey drift response of the example building with friction damper, visco-elastic damper and the viscous damper is done when subjected to 10 ton and 100 ton of blast-induced ground motion. From this comparison, it can be concluded that viscous damper is more effective to reduce the drift response in all floor level.

In figures 6 and 7, a typical time-history response, i.e. inter-storey drift and absolute acceleration of example structure subjected to case C (100 ton) blast-induced ground motion are plotted for the free frame, Braced frame, and frame with considered dampers for the first floor of the example frame. The viscous damper is observed to be more effective in controlling the peak inter-story drift and maximum absolute acceleration when compared to other dampers.

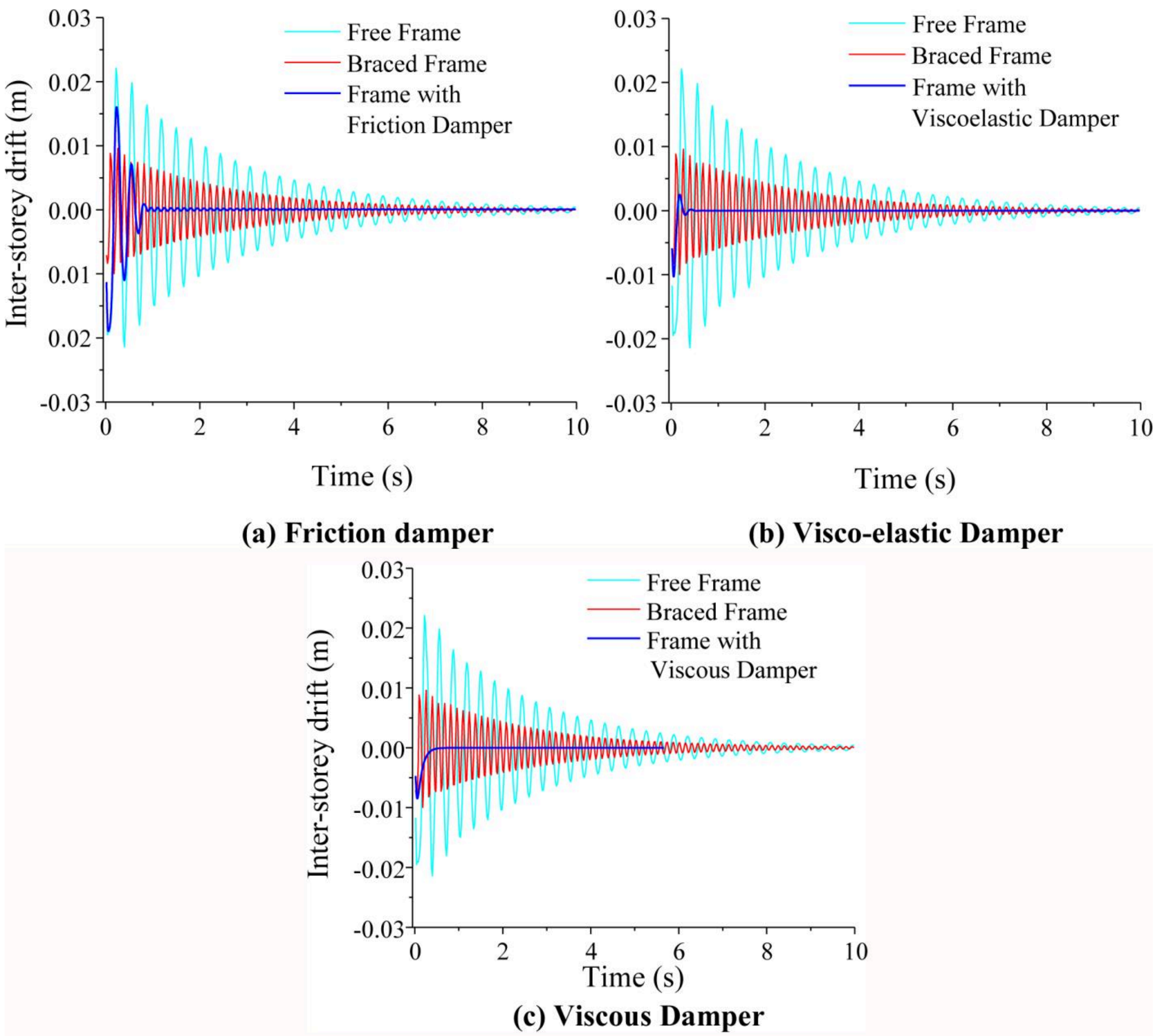

Figure 6. Inter-story drift response at the first floor level of the example structure with various dampers subjected to 100 ton of blast-induced ground motion

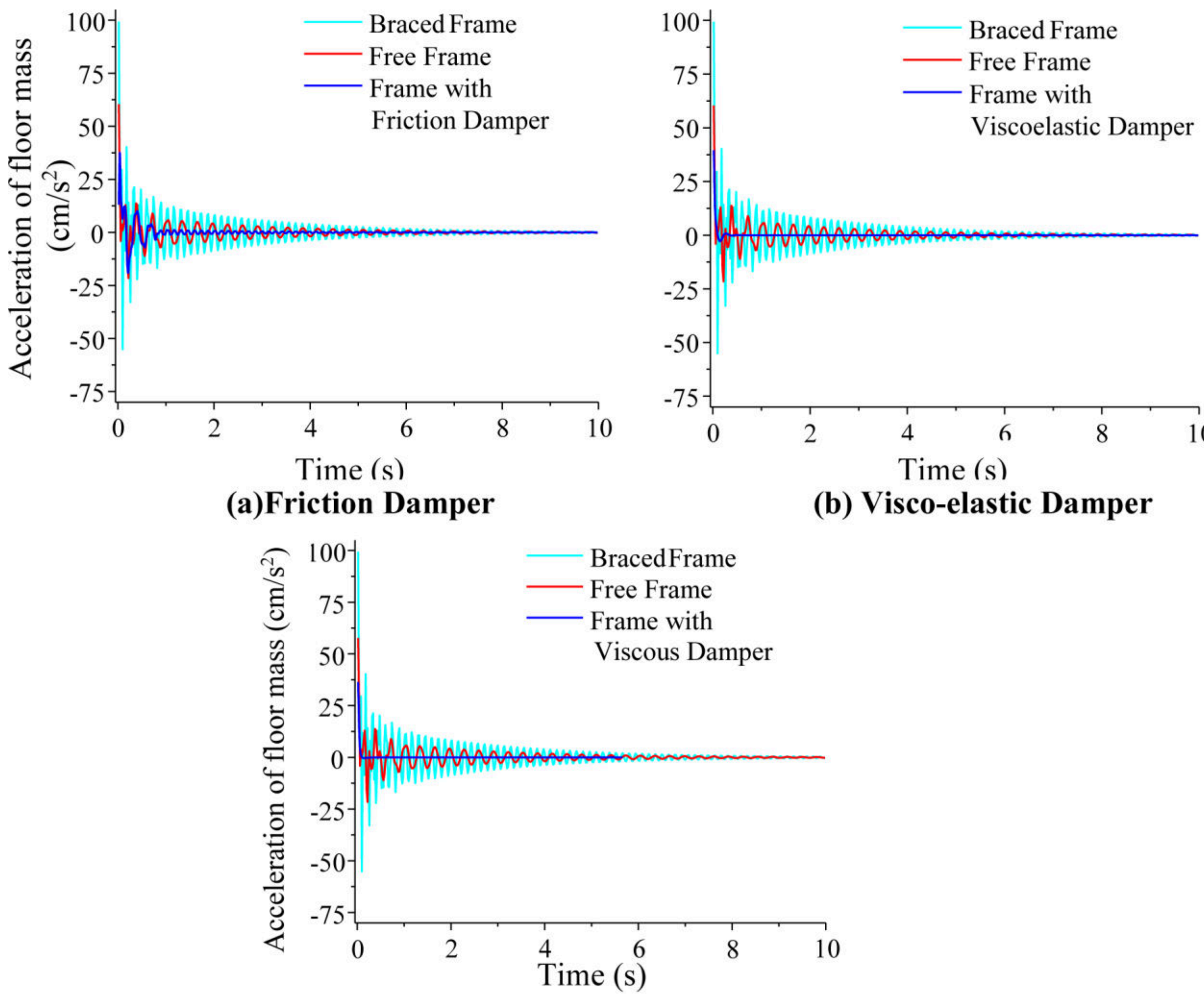

Figure 7. Absolute acceleration response at the first floor level of the example structure with various dampers subjected to 100 ton of blast-induced ground motion

The effectiveness of friction based energy dissipation system using the Coulomb friction model has been investigated. The floor displacement of structure with friction damper can be reduced by 25% to 60% of the peak floor displacement at all floor levels with reference to free frame structure response. The reduction in floor displacement is not seen in any ground motions when compared to Braced frame, since the friction damper has smaller bracing stiffness than that of the braced frame thus resulting in larger drifts. In case of the viscoelastic damper, the floor displacement can be reduced by 35% to 55%, whereas in case of viscous damper reduction is found to be 55% to 75% of the peak floor displacement of the free and braced frame structure. It is observed that the base shear increases when bracings are added to the free frame structure. Addition of damper results in a decrease of base shear for all ground motions in comparison to both free fame and braced frame. Among the dampers, viscous dampers are found to be most effective in reducing the base shear of the structure in comparison to both. A comparison of base shear, inter-story drift (first-floor level) response and absolute acceleration (first-floor level) response of the example structure is presented in Tables 2–4.

The base shear is decreased in the structure with a viscous damper by more 7% in comparison to structure with friction damper, while a reduction of up to 30% is observed in comparison to the frame with viscoelastic damper. The inter-storey drift at first floor level in the structure with viscous damping is reduced by 25% to 38 % more than that of the structure with friction damper and 3% to 5% more in comparison to the structure with viscoelastic damper. The absolute acceleration response of the example multi-storey building has been reduced more i.e. 15% to 44 % at first-floor level, for example, frame with viscous damper when compared to a frame with friction damper and frame with viscoelastic damper. While all the dampers are found to be effective in reducing the responses of the structure, viscous dampers are found to be the most effective in controlling these responses among other dampers considered in this study.

Table 2: Base Shear of Example building when subjected to ensemble of Blast Induced ground motions (case A, B and C)

Ground Motions	10 TON	50 TON	100 TON
Free Frame	140.59	458.94	758.98
Braced Frame	314.17	1024.54	1695.99
Frame with the Friction damper	130.75	438.22	704.26
Frame with Viscoelastic damper	180.25	611.25	1000.12
Frame with Viscous damper	121.55	396.40	656.19

Table 3: Interstory drift (m) (First-floor level) of Example building when subjected to an ensemble of Blast-Induced ground motions (case A, B, and C)

Ground Motions	10 TON	50 TON	100 TON
Free Frame	0.00415	0.0135	0.0224
Braced Frame	0.00186	0.0062	0.010
Frame with Friction damper	0.00215	0.0067	0.0140
Frame with Viscoelastic damper	0.00199	0.0065	0.009
Frame with Viscous damper	0.00161	0.00524	0.00867

Table 4: Absolute Acceleration (cm/sec^2) (First floor level) of Example building when subjected to an ensemble of Blast-Induced ground motions (case A, B, and C)

Ground Motions	10 TON	50 TON	100 TON
Free Frame	11.18	36.54	60.40
Braced Frame	18.41	59.99	99.34
Frame with the Friction damper	10.40	36.02	59.80
Frame with Viscoelastic damper	6.8	23.8	39.51
Frame with Viscous damper	5.912	21.97	36.17

CONCLUSION

The effectiveness of energy dissipation systems in controlling the response parameters when compared to free frame and braced frame structure has been investigated in this paper for a five storey example frame structure. Based on the investigations presented in this paper, the following main conclusions can be drawn:

Adding stiffness to the frames by mean of bracings does not always solve the purpose of strengthening of stories. Although the introduction of bracings in the frames can control the drift response parameters, it increases the absolute acceleration and base shear responses of the frame.

The viscoelastic damper can reduce 25% to 60% of the inter-story drift and 20% to 48% of the absolute acceleration of example multi-story frame with respect to free and braced frame without damper under different blast-induced ground motions. The reduction of base shear, inter-story drift, and absolute acceleration is found to be in the range of 33%–70%, 35%–75%, and 30%–60% respectively for the example frame with viscous damper. The viscous damper is found to be the most effective damper among the dampers considered in this study for response reduction for a different type of blast-induced ground motions.

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Policy Issues in Affordable Housing Made with Bamboo Reinforced Structural Component

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ABSTRACT

World population is growing at a rapid pace which has caused a tremendous housing shortage. This in turn leads to over exploitation of natural resources such as iron ore, lime stones, alumina, etc. This has resulted in exponential increase in the prices of conventional building materials. Also the production of these materials causes the degradation of environment due to the production of greenhouse gases. To resolve this menace, recent researches have been focused on developing sustainable infrastructure. Numerous innovative techniques have been showcased by different researchers recently, highlighting the potential of bamboo based construction for sustainable infrastructure. However, for onsite construction these innovative techniques have still not been widely used to develop affordable housing. This study focuses on the available techniques and the hindrances affecting the mass usages of such techniques to develop affordable housing. An overview on the benefits and shortcomings of different components such as bamboo reinforced beams, bamboo reinforced columns, bamboo arches, bamboo reinforced walls are also analyzed here for affordable housing. It was observed that such bamboo based structures have great future prospects for developing affordable housing as they are cheap and have considerable strength. However, issues such as bond stress, chemical treatment, size, shape, species, age, moisture content, etc. which affect the bamboo performance have still not been standardized through guidelines. Therefore, there is an immediate need to standardize structural bamboo through effective guidelines for its wide application.

KEYWORDS: Affordable Housing; Bamboo Reinforced Construction; Sustainable Infrastructure

1. INTRODUCTION

Cement and steel are the most widely used building materials in construction industry. However, they are also the most polluting ones. The average cost per unit of these materials has risen sharply over the years due to excessive demand. Developing countries are mostly affected due this trend of construction. Therefore, futuristic construction needs sustainable construction practices. Bamboo, coconut coir, jute and sisal are some of the alternatives which can resolve these issues (Javadian et al. 2016).

Bamboo as an alternative to steel has been researched upon recently. Bamboo belongs to a unique group of gigantic grasses which grows naturally in many regions across world. It grows in the tropical zones which coincide mainly in developing countries where the highest rate of urbanization and population growth is observed (Javadian et al. 2016). Bamboo has more than 1250 species across the world (Scurlock et al. 2000) with some species growing at more than 91 cm per day (Guinness book of world records 1999). The species usually attain a maximum height of 15 – 30 m and takes 3–8 years to reach its maximum strength with a diameter of 5 – 15 cm (Li et al. 2012). Every ton production of bamboo exhales oxygen in the atmosphere while absorbing about a ton of CO_2 from the atmosphere which makes it as an excellent eco-friendly material (Bhalla et al. 2008).

Bamboo has excellent material properties useful for developing infrastructure. Tensile strength of some of the species of the bamboo is reported to be much more than mild steel (Jindal 1986). Excellent strength to weight ratio of bamboo makes it a good alternative to steel (Bhalla et al. 2008). Over the years, researchers on bamboo have highlighted its several advantages and disadvantages (Table 1) over the use of conventional steel.

Table 1. Advantages and disadvantages of bamboo in construction

Advantages	Disadvantages
High tensile strength	Prone to attacks by fungus and termites
Naturally available material	High rate of water absorption and shrinkage
Eco-friendly	Mechanical properties vary with species
High strength to weight ratio	Presence of node which affects tensile strength
Fastest growing plant	Flammability
Low cost and low energy for production	Long term durability issues
Acts as a carbon sink	Chemical decomposition due to alkaline environment
Widely available especially in developing countries	Variation of properties with moisture content

Bamboo potential in the construction industry is un-ignorable. Traditionally bamboo is used for walling solutions in many developing countries. Continuous research efforts on the development of bamboo as a building material have shown significant positive results over the years. However, there are still many issues hampering its effective utilization. This paper analyzes the potential of bamboo in construction industry by analyzing the techniques for development of different structural components such as bamboo reinforced beams, bamboo reinforced columns, bamboo arches, and bamboo reinforced walls and issues affecting its wide application.

2. BAMBOO BASED INFRASTRUCTURE

Mankind has evolved the construction techniques over the decades as per need. Housing evolution can be seen from mud housing to prefabricated units in different countries. Enormous urbanization in developing countries is facing the wrath of steel prices making construction expensive, this showing the need of bamboo in construction. Research on bamboo as a replacement of steel has shown positive outcome in this regard.

Bamboo was first researched upon in 1914 wherein the small diameters of bamboo and bamboo splits as reinforcement in concrete were tested (Chow 1914). However, considerable research in the last four decades has established the potential of bamboo in construction industry. Recent advances in the sustainable infrastructure developed with bamboo reinforcement for different structural components are presented below.

2a. Bamboo Reinforced Beams

Traditionally reinforced concrete beams are developed using steel bars as reinforcement. As per the structural conditions, the beams are either under or over reinforced with pre-defined guidelines for their application. Indian codal guidelines (IS456: 2000) recommend a maximum reinforcement of 4 percent of cross-sectional area of beam. However, for bamboo there are no standardized guidelines. Bamboo as reinforcement in beams was studied (Ghavami 2005). Bamboo reinforcement studied was between 0.75 to 5 percent of cross sectional area. At 3 % of treated bamboo reinforcement, beams ultimate load was 400% as compared to beams without reinforcement (Figure 1). In a different study it has been demonstrated that the treated bamboo reinforcement enhances the load carrying capacity significantly (Agarwal et al. 2014). Also the ductile behavior is observed in bamboo reinforced beams. Beams with highest bamboo reinforcement and concrete compressive strengths did not necessarily give the highest load carrying capacity Different materials were used for stirrups to test the performance of bamboo reinforced beams (Mark and Russell 2011). Steel stirrups provided the highest load whereas beams with no stirrups had the lowest load carrying capacity. Research results demonstrated that bamboo as reinforcement enhances the ductility and load carrying capacity of beams. However, the shape of reinforcement, physical characteristics, chemical treatment details etc. which affect its performance are not stipulated.

2b. Bamboo Reinforced Columns

Performance of bamboo in compression has also been researched upon by several researchers. (Leelatanon et al. 2010) used bamboo as a reinforcing material for development of short columns. Short columns (125 mm × 125 mm × 600 mm) with different type of reinforcements under concentric loading were tested to investigate their strength and ductility. It was observed that addition of untreated bamboo reinforcement could resist the axial load requirements as per code (ACI318: 2014) but ductility was low especially for 1.6% reinforcement ratio. Research also highlighted the shortcomings of bamboo application such as high rate of water absorption affecting its bonding (Figure 1). However, for treated bamboo reinforcements much higher strengths and ductility was observed. Ghavami (2005) analyzed the performance of bamboo reinforced columns treated with sikadur 32 Gel. It was observed that the guidelines regulation for load sustainability by beams can be fulfilled by 3% treated bamboo reinforcement as per brazilian norms. Agarwal et al. (2014) studied the axial performance of treated, untreated bamboo reinforced columns with steel reinforced columns. It was observed that load carried by 0.89% steel reinforced columns was comparable to the bamboo reinforced column with 8% reinforcement under axial and transverse loading. The poor performance of untreated bamboo reinforcement due to its water absorption which affects the bond strength was also highlighted. Based on the performance of bamboo reinforcement in axially loaded members it was concluded that it can replace steel reinforcement if used in guided manner. However, no predefined codal guidelines on its application affect its potential use.

2c. Bamboo Arches

Bamboo has excellent strength to weight ratio which makes it suitable for arches. Researchers have evaluated the performance by developing different types of bamboo based arches. (Korde et al. 2014) developed bamboo concrete composite parabolic tied arches. The developed arches had a span of 4.5m with a rise to span ratio of 0.2. The arches were tested under uniform loading. It was observed that bamboo concrete (bamcrete) parabolic tied arches behave as linear non elastic flexible structures to a compressive stress limit of 10 MPa. Bamcrete arches utilizing the bamboo potential were developed (Korde et al. 2008). It was also observed that a 4.7m span loaded with 880 kg deflected by 17 mm initially and further by 17 mm in 2 months due to creep.