Seismic Energy Dissipation: Art of the Scenario

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Abstract - *Over the past decades, the ductility based conventional methods are being used for earthquake resistant design of structures. During a major earthquake, life safety can be achieved to the required level by these methods, but they do not ensure the required damage control which restricts the functional use of the structure after the major earthquake. In order to overcome this drawback, in recent times, considerable attention has been given to the innovative, non conventional methods of earthquake resistant design techniques such as seismic base isolation systems, passive energy dissipation systems, active, hybrid and semi active control systems. These innovative methods are found to be more reliable and effective means of earthquake hazard mitigation. In this paper an attempt has been made to give the overview of these non conventional systems which includes the concept of seismic base isolation, types, advantages and limitations of base isolation systems, the working principle, advantages and limitations of different passive energy dissipation devices and the basic working principles of active, hybrid and semi active control systems.*

Key Words: Energy dissipation, Non conventional methods, Base isolation, Dampers, Control systems.

1. INTRODUCTION

During a major earthquake, a huge amount of energy will be induced into the structure. The level of damage to the structural system depends on the way in which the structure dissipates the input seismic energy. In conventional method of earthquake resistant design, the energy dissipation is achieved by material ductility. This method ensures life safety but does not ensure required damage control and hence the functionality of the structure after the earthquake becomes questionable. The required structural performance can be achieved by introducing non conventional methods of earthquake hazard mitigation techniques like base isolation, passive energy dissipation devices, active, hybrid and semi active control systems.

In seismic base isolation, the energy transferred to the superstructure is considerably reduced by decoupling the superstructure and substructure. The entire superstructure acts as single unit and hence the inter storey drifts becomes negligible.

In passive energy dissipation systems, a major portion of input seismic energy is dissipated by means of mechanical devices which may works on different principles like friction, shear deformations, metallic yielding, and fluid orificing etc. Thus the forces induced in the primary structure will be considerably reduced which consequently decreases the ductility demand of the structure.

In active control systems, an algorithm based control unit along with actuators and sensors is used to reduce the response of the structure. In hybrid and semi active control systems passive energy dissipation devices are embedded with active control systems to get desired structural control.

2. SEISMIC BASE ISOLATION

In this approach, the structure is not fixed to the ground firmly. The superstructure and substructure are separated by means of elastic medium which acts as a barrier to the earthquake forces otherwise being transmitted to superstructure causing damage or failure of structure. The large amount of energy being transmitted by earth to the structure during earthquake is being overcome by the displacement of the elastic medium, thus ensuring the structural safety and integrity.

Base isolation is an external type of system, works in passive way and inculcates a method of seismic response control by adjusting stiffness and damping.

Elastic medium is made up of natural or synthetic rubber which has very high vertical stiffness in order to carry the vertical loads of structure and very high lateral flexibility in order to undergo displacement under the action of earthquake forces.

The fundamental principle behind the seismic base isolation is as follows:

- Decoupling the superstructure and substructure by means of elastic medium thus lengthening the fundamental natural period of structure.
- Energy dissipater or dampers in order to minimize the relative displacement of structure and its support.
- Providing enough rigidity in horizontal direction so that the structure acts like a fixed structure under minor earthquake and wind.

Schematic representations of conventional and isolated building under earthquake force are as shown in fig.1.

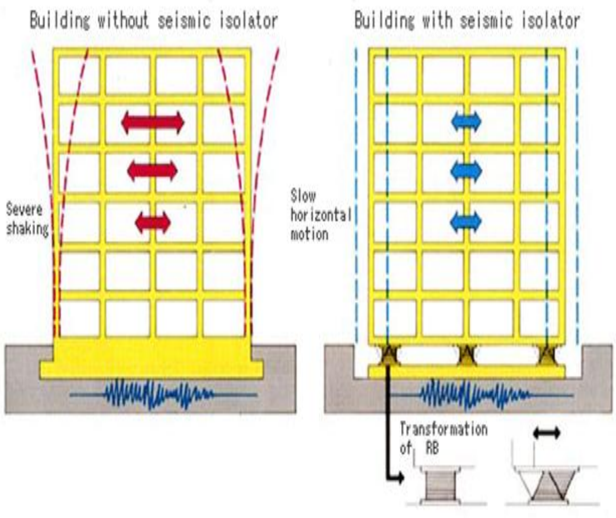

Fig -1: Response of building without and with isolator under earthquake forces

From Fig.1, it is clear that building without base isolators is subjected to large inter storey drift which is the main cause for damage and even may collapse. However in building with base isolators, the superstructure acts like a rigid body with large displacements due to introduction of elastic medium. Therefore, in isolated buildings the lateral forces are largely reduced thus ensuring structural safety and integrity.

2.1 Types of Seismic Base Isolators

Many types of seismic isolators are being developed during the course of time. Most commonly used in practice are sliding systems and elastomeric (rubber) bearing systems.

Sliding systems

These are simple in concept. It consists of a concave surface at bottom over which the superstructure is made to rest. Under the action of the earthquake force, the superstructure undergoes displacement in the predefined constraints of sliding system. The original position of the superstructure is regained due to the restoring force produce because of concave bottom surface. Figure 2 illustrates the sliding system,

Elastomeric (Rubber) bearings

These are made up of horizontal layers of natural or synthetic rubbers in the form of thin layers bonded by steel plates. Steel plates are introduced to ensure that bearing does not undergo excessive bulging under large vertical loads. These are most commonly adopted for isolating the buildings. There are many types of rubber bearing isolators such as plain elastomeric bearings, lead rubber bearings and high damping rubber etc.

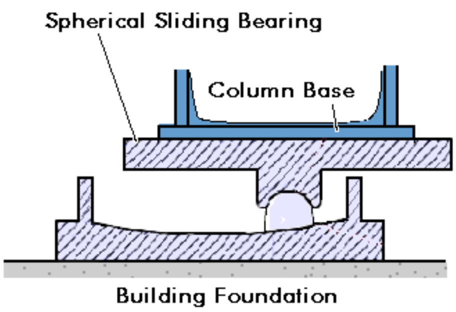

Fig- 2: Mechanism of sliding type base isolation system

Plain elastomeric bearings are made up of elastomeric rubbers which undergo excessive bulging due to high vertical loads. Thus these types of isolators are not used in nowadays. Fig.3 illustrates plain elastomeric rubber bearing.

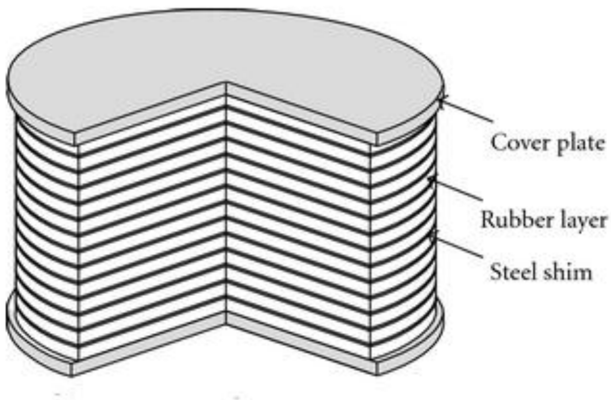

Fig-3: Elastomeric bearing

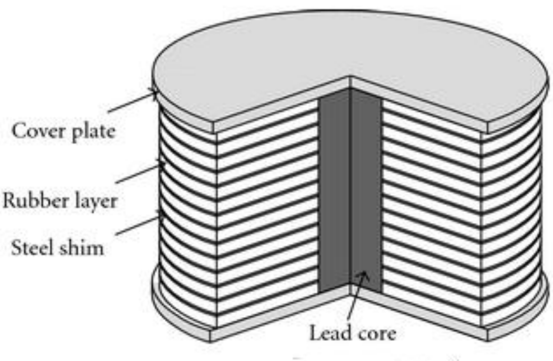

Fig-4: Lead rubber bearing

Lead rubber bearing consists of thin horizontal layers of rubber which are bonded to steel plates to avoid excessive bulging under high vertical loads and a central lead core is introduced to have a damping effect in order to reduce the excessive displacement. Fig.4 illustrates lead rubber bearing. The William Clayton Building in Wellington, New Zealand was the first building to be base isolated using lead rubber bearings in 1981.
High damping rubber bearings are similar to the lead rubber bearing, except the rubber used to manufacture the isolator. The rubber used in this bearing is of high quality and has high damping effect.

2.2 Outcomes by Introduction of Base Isolation

- Increase in the fundamental natural period of structure.
- Reduction in response acceleration.
- Structural damage is restricted or negligible.
- Functionality of building is ensured even after severe earthquake which is essential in case of building such as hospital, communication center etc.
- Reduction in inter storey drift.
- Slender structural member can be adopted due to reduction in transfer of earthquake force to the structure.

2.3 Limitations of Base Isolation

- Initial cost of base isolated building comes out usually higher than conventional building due to additional cost of isolators and its installation.
- As the height of the building increases, the superstructure cannot act as a perfect rigid body and base isolation becomes ineffective. Therefore it is applicable to limited height.

3. PASSIVE ENERGY DISSIPATION (PED) SYSTEMS

These systems compose of materials and devices, which enhances damping, stiffness and strength, and can be used for both rehabilitation of structures and new construction. These systems are characterized by their energy dissipating capacity in the structural systems in which they are installed. These types of devices are always ready to perform to their capacity and their capacity do not depends on the excitation force. The different types of passive energy dissipating devices along with their working principles are described below.

3.1 Visco Elastic Dampers

This type of materials are usually made up of visco elastic materials like copolymers or glassy substances like Bitumen Rubber Compounds, thermoplastic rubber etc. These materials have good adhesive strength, can undergo large shear deformations and can take the form of a thin sheet. These types of materials are sensitive to temperature, strain and other environmental factors. Visco elastic dampers consist of thin steel plates and visco elastic material sheets which are laminated alternatively as shown in Fig – 5. Visco elastic dampers work on the principle of large shear deformations. When a vibration is induced in a structure due to an earthquake, relative motion occurs between the outer plates and centre plate, due to which a shear deformation occurs in the visco elastic materials and hence the energy is dissipated.

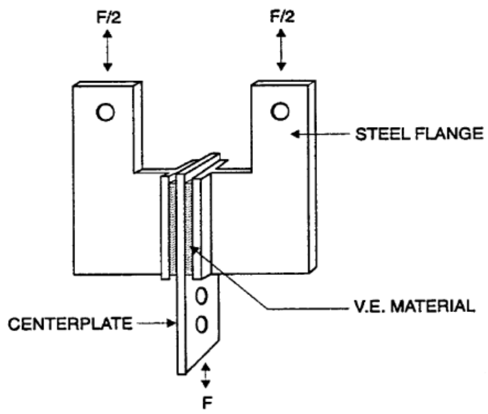

Fig – 5: Visco Elastic Damper Configuration

From many researches it has been shown that approximately more than 30% reduction in the structural response can be achieved by using visco elastic dampers. As the visco elastic materials are sensitive to temperature and other environmental factors, proper analysis of the material has to be done before the design of visco elastic dampers.

3.2 Metallic Yield Dampers

This is also one of the effective ways of energy dissipation which works on the principle of dissipation of energy by inelastic deformations of metals. In most of the metallic yield dampers, mild steel plates of triangular or X shape are used so that uniform yielding throughout the material can be achieved. Fig – 6 shows a typical X shaped plate damper or ADAS (Added Damping And Stiffness) device. When vibrations are induced in the structure due to an earthquake, the provided metallic yield damper yields first, dissipating a major portion of seismic energy and hence reduces the energy input into the structure and safeguards it.

An unbounded brace or tension/compression yielding brace shown in Fig – 7 is another type of damping device which works on the same metallic yielding principle. It consists of a core plate encased in a concrete or mortar filled steel tube. The core plate provide a stable energy dissipation by yielding under reversed axial loading, while the surrounding concrete filled steel tube resists compression buckling.

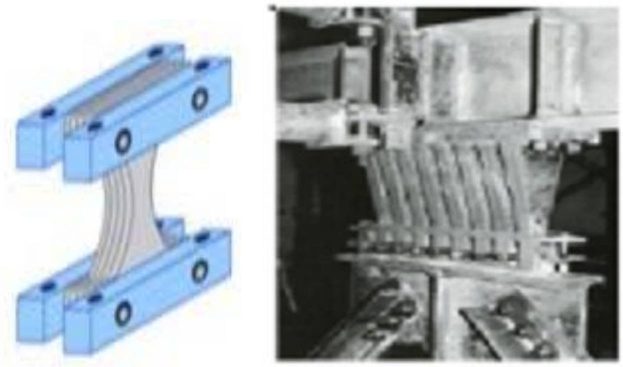

Fig – 6: Metallic Yield Dampers

The disadvantage of metallic yield dampers is they need regular inspection as there is a chance of premature fracture of the devices due to fatigue caused by strong wind loads. This type of dampers generally needs to be replaced after the major earthquake.

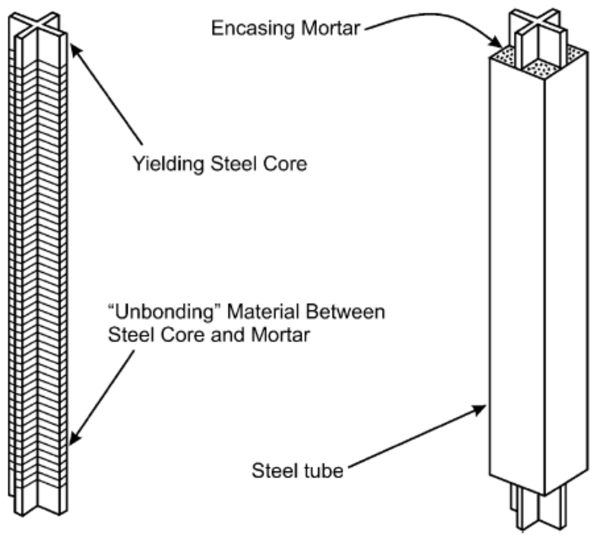

Fig – 7: Unbonded brace

3.3 Friction Dampers

The energy dissipation in a friction damper is similar to the dissipation of kinetic energy of a moving vehicle by the use of friction between tyre and the road. Several friction damping devices have been tested experimentally namely, Pall, Fitzgerald, Sumitomo, Constantinou, Dorka, Grigorian etc. and some of these have been used in the structures around the world. Friction dampers generally possess large, rectangular and nearly stable hysteresis loops thereby indicating high energy dissipation capacity.

Pall friction dampers consist of series of steel plates which are specially treated to develop reliable friction. These plates are clamped together with high strength steel bolts and allowed to slip at a predetermined load. These friction dampers are designed not to slip during wind storms and moderate earthquakes. During a major earthquake they slip at a predetermined load and dissipate a large portion of energy allowing the building to remain elastic or delays the yielding. Hence the damage to the primary structure is significantly reduced.

In case of rotational friction dampers, the bolt connects three steel plates and between these plates there are two circular friction pad discs (as shown in Fig-8), which ensure stable friction force and reduce noise of the movement. The central plate will be connected to the beam of the frame structure by a hinge and the side plates are connected to the bracing systems. During a major earthquake when the horizontal force exceeds the frictional forces, sliding starts and the central plates rotates relatively to the friction pad discs and thereby dissipates major portion of seismic energy.

The friction dampers are inexpensive and not affected by environmental factors like temperature, stiffness degradation due to ageing etc. In most of the times they do not need repair or replacement even after the earthquake and can perform multiple times and also do not need regular inspection. Compare to other types of dampers friction dampers have high damping capacity and hence require less number of dampers for a particular structure. The cost of the structures with friction dampers will be much less compare to that of moment resisting frames, especially in the regions of high seismic activity.

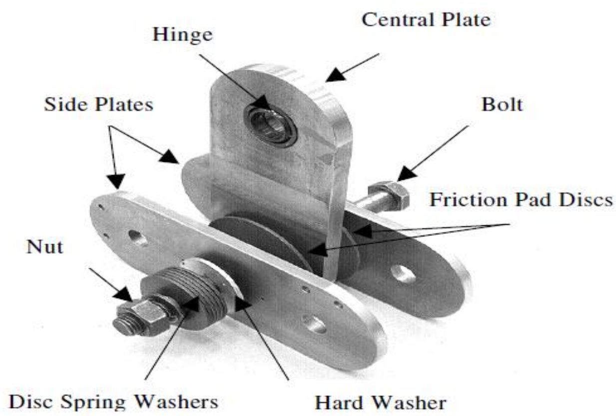

Fig – 8: Details of rotational friction damper

3.4 Viscous Fluid Dampers

This type of dampers works on the concept of fluid orificing in which energy is dissipated through the movement of a piston in a highly viscous fluid. A viscous fluid damper consists of a piston containing number of small orifices, within a damper housing filled with a compound of silicone or similar type of oil as shown in Fig – 9. When vibrations are induced in the structure due to an earthquake the piston moves, which causes the viscous fluid to move from one side to the other through small orifices, thereby dissipates a large amount of energy and safeguards the structure. In many of the practical applications, viscous dampers are used in combination with the seismic base isolation systems.

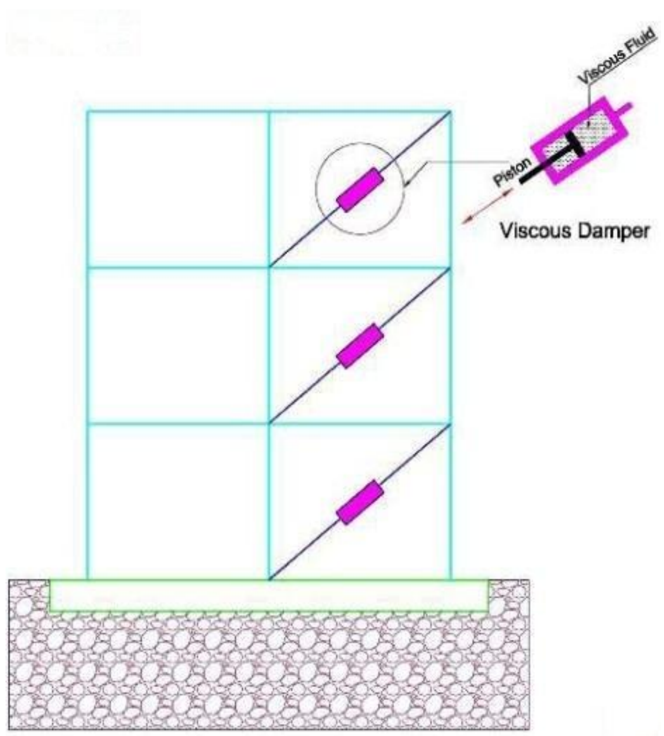

Fig – 9: Viscous Fluid Dampers

3.5 Tuned Mass Dampers

Earlier these types of dampers are used for mitigation of wind induced excitations and several researches were done to implement them to reduce hazards due to seismic excitations. A passive tuned mass damper (TMD) can only be tuned into a single frequency of the structure and hence response of the structure can be significantly reduced by tuning it into resonant frequency. These types of dampers have higher mass compare to other dampers. These tuned mass dampers are generally used in combination with active systems such as active mass dampers and hybrid mass dampers.

3.6 Tuned Liquid Dampers

This works on the similar principles of Tuned Mass Dampers (TMD). In effect, a secondary mass in the form of a body of liquid is introduced into the structural system and tuned to act as a dynamic vibration absorber. They have their primary applications in controlling wind induced vibrations. When compare to TMDs Tuned Liquid Dampers (TLD) include low initial cost, ease of frequency tuning and virtually free of maintenance.

4. ACTIVE, HYBRID AND SEMI-ACTIVE CONTROL SYSTEMS

4.1 Active Control Systems

In an active control system the resistant forces are not fixed and are dependent on the external excitation. This system is a combination of computer science data processing, sensing technology, structural dynamics and wind and earthquake engineering. An active control system consists of sensors located about the structures to measure both external excitations and structural response, controller unit and actuators. During seismic excitations, the sensors measure the accelerations at the structural base and send it to the computer control unit. The computer control unit processes the measured information and using the control algorithm given to the control unit, it computes the required control forces and sends it to the actuators. The actuators are usually powered by external sources and they produce the required control forces. At the same time, the structural response to the external excitations is also measured by the sensors and is processed by the control unit. The control unit computes the control forces such that only the least structural response is possible. These types of systems are applicable for multi hazard mitigations, like it can be used for both wind and seismic excitations. The response control is most effective in this system. But it requires a continuous power source, fail in which may lead to disaster. The schematic representation od active control system is as shown in Fig-10.

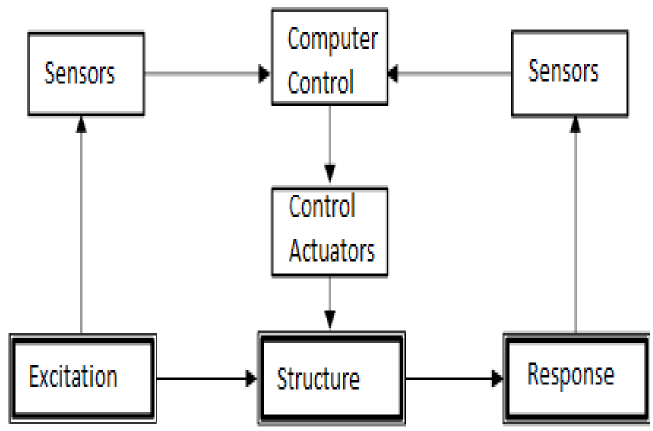

Fig – 10: Schematic Representation of Active Control System

4.2 Hybrid Control Systems

It is a combination of active control and passive dissipation systems. The power required to operate this type of system is comparatively much less than that of an active control system. In this type of system a portion of the energy is dissipated by passive energy dissipation devices and hence load on the active control system is reduced and consequently required power is also less. A side benefit of hybrid system is that, in case of a power failure, the passive components of the control still offer some degree of protection, unlike a fully active control system. The schematic representation of hybrid control system is shown in Fig-11.

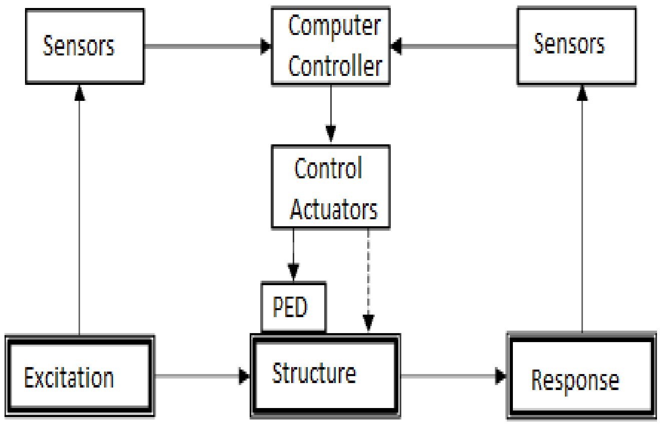

Fig – 11: Schematic Representation of Hybrid Control System

4.3 Semi Active Control Systems

This type of system is similar to the hybrid control system. The difference between the two systems is, in semi active control systems control actuators do not add mechanical energy directly into the structure. Hence they are also often called as controllable passive devices. Due to the presence of PEDs this system also has a benefit of partial protection even in the case of a power failure, similar to the hybrid control systems. The schematic representation of semi active control system is shown in Fig-12.

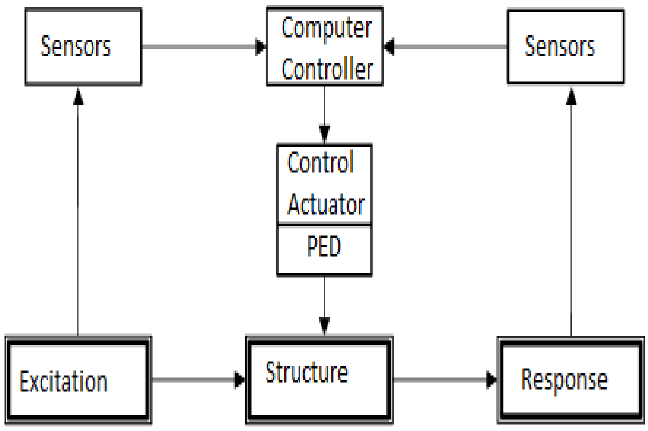

Fig – 12: Schematic Representation of Semi Active Control System

5. CONCLUSIONS

The following conclusions can be drawn by considering various non conventional methods of earthquake resistant design as described above.

- These non conventional methods found to be more reliable and effective earthquake resistant design techniques, with a good reduction in response of the structures when compared to conventional methods.
- By adopting the above systems, the dependence on the ductility of the system can be significantly reduced.
- In case of severe earthquakes, significant damage control can be achieved by adopting non conventional methods when compared to conventional ductility based earthquake resistant design. This facilitates the functional use of the structure even after a major earthquake, which is a must in case of hospitals, communication centers etc.
- The cost of these non conventional systems is higher than that of conventional systems. However, by considering the long term effects and performance, the non conventional systems may found to be economical and effective.
- As these non conventional systems are still evolving technologies, proper modeling, analysis and design are required before implementing in large scale. Proper installation, care and maintenance are to be ensured for efficient performance of these systems, fail in which may lead to big disasters.

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