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Sustainable Smart Structures

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***Abstract:*— A structure malleable to the altering environmental conditions can be termed as a Smart Structure. Smart structures sense the changes in the structure when they are subjected to extreme conditions like vibrations. Smart structures sense and inform the user about the damages in the structure. They alter the material characteristics and properties to sustain or to prevent the damaging effects on the structure. They also optimize the performance of the structure under critical conditions. Some of the factors disturbing structural health are Differential Settlement, Earthquakes & Vibrations, Structural Distress and Corrosion of Reinforcement. This paper discusses these factors and smart or intelligent ways to prevent it. The smartness of the structure can be achieved by smart materials resulting from molecular modification to variable energy conditions. Smart materials Shape-Memory Alloys (SMA), Magneto- Rheological Fluids, Non-Corrodible Materials, etc. are used to deal the factors affecting structural health.**

***Index Terms*— SMAs (Shape memory alloys) OMC (optimum moisture content) PVDF (Polyvinylidene fluoride)**

I. INTRODUCTION

It is said that earthquakes occur every fraction of a second. But it is of so low scale (measured on Ritcher Scale) that is goes unnoticed. Low frequency earthquakes damage the structure to a neglible value if occurred for a few seconds. But as mentioned earlier earthquakes are persistence. Continues low frequency vibrations have damaging effects on the structures. Over the years major focus has been on the development of repairing techniques for the damages caused by earthquakes and vibrations. Techniques like pusher piers, base isolation, retrofitting, etc have proved to be very beneficial and reliable. Some of these techniques reduce the effect of earthquake on structures. But this is at a very small scale with large investments. It is time to design structures which could sustain the unexpected loads and reduce the intensity of damages. Smart structures prevent the damages to a considerable extent. This paper converse few of the factors damaging structures and their prevention using advanced materials.

II. DIFFERENTIAL SETTLEMENT

Differential settlement is one of the causes for severe structural damages. After the construction of any structures is completed some settlement in its foundation is customary. In this paper settlement deals with the consolidation of soil (cohesive) which should be under control. Different countries allow different allowable settlement values measured in mm (millimeter). For a foundation with isolated footings this settlement may vary under each footing. Raft foundations are widely known to counter this uneven settlement to a large extend. Even base of a raft foundation reportedly causes even settlement. Even settlement reduces the reimbursement in the structure. However a raft foundation is not feasible in all cases.

Fig. 1 shows a diagonal crack in the shear wall at the junction. This is one kind of crack which results from differential settlement.

Fig. 1 Damage in shear wall due to uneven settlement.

For a saturated soil mass, the unequal settlement impact on the structure is very significant. Soil may collapse from underneath of the foundation leaving a part of the structure settled more than that of the rest. More the water in the soil mass more is the expulsion of it and more is the settlement. It is known that the volume of soil remains unchanged at OMC (optimum moisture content). Volume being a product of mass and density with mass remaining a constant, density remains the only variable term and hence its effect is different at different values.

If we maintain the OMC, the density of the soil is maintained and hence the settlement can be controlled.

A smart way to maintain the OMC is to not allow water to reach and stay in the dynamic area of soil for longer period of time. It means that the excess water has to be removed at a faster rate before it disturbs the dense molecular pact of the soil.

To achieve this a new method adopted is electro-osmosis. Electro-osmosis is a method of expulsion of water from cohesive soils using Direct Current. When a direct current is passed through a saturated soil a positive electrode (anode) and a negative electrode (cathode), pore water migrates to the cathode. Now this cathode in general attracts water molecules to itself.

This cathode and anode grid can be arranged in different ways i.e., vertically (as shown in Fig. 3), horizontally (as shown in Fig. 2). The process can also be carried out on site for a smaller area.

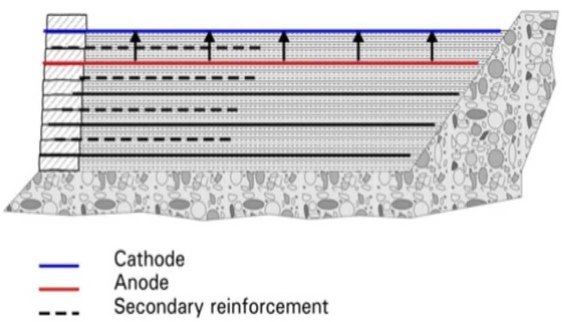

Fig 2. Horizontal arrangement of grid.

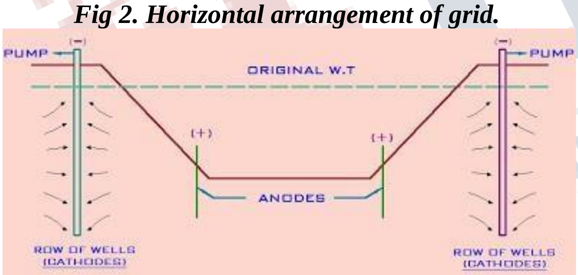

Fig 3. Vertical arrangement of grid.

As shown in Fig. 3 when the water reaches the cathodes, it can be pumped out easily and the OMC of the soil can be maintained. In case of ground improvement, steel rods are used as anode and perforated pipes as cathode. The water can also be pumped to a destination like an open well or reservoir for potential benefit.

III. EARTHQUAKES AND VIBRATIONS

The structural damages by earthquakes and vibrations due to nuclear bomb testing, rocket launching, volcanoes are irreparable with high intensity of shocks. This in particular triggers the vulnerable parts of the structure i.e., joints. Structural Damages caused by vibrations are not swift in most of the cases. It is a long term process which clearly gives enough warnings before collapse. Earthquake last for seconds. It has a very high frequency, high enough to cause permanent damage to the structure.

It is to be noted that the damage is not owed by the intensity of shock, but owed by the lateral movement of the structure for which a structure is not designed. Earthquake resistant structures are designed with reference to the ductile detailing codes which focus on strengthening the areas of high shear and lateral forces. These structures counterbalance the external lateral force and fetch some rescue time for the inhabitants. However, the damage caused is of severe intensity.

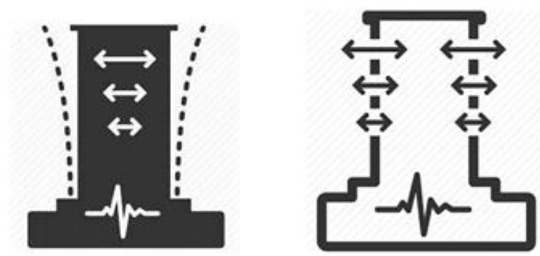

Fig 4. Lateral displacement of structure

Magneto-Rheological fluids act as a damper and control the dynamic horizontal displacement of the structure. They reduce the acceleration due to earthquakes.

Fig. 4 shows the sway of the building and the lateral displacement due to earthquake. It is to be noted that the acceleration is experienced by the substructure. However, superstructure experiences the effect of the shocks while undergoing lateral displacements.

A magneto-rheological fluid is fundamentally iron particles with a base liquid confined in electro magnets. The particles at rest i.e., before the activation of magnets would be freely dispersed in the base liquid say oil. But when earthquake strikes these magnets can be activated and the particles will form a stiffer layer in the direction of flux lines. Activation of magnets will solidify the complete solution which acts as a damper.

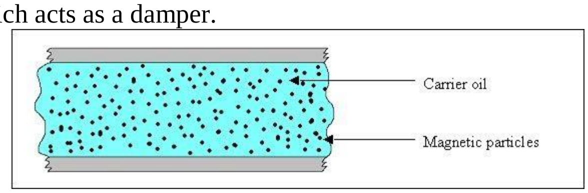

Fig. 5 Particles state when magnets are deactivated

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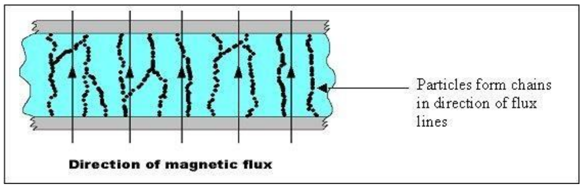

Fig. 6 Particles state when magnets are activated

It can be provided by filling the rheological fluid in a magnet confined casing surrounding the footing with a connector opening at the top.

IV. STRUCTURAL DISTRESS

Unexpected loading conditions may cause structural distress causing slight to severe damages to the structure. To encounter these, a higher factor of safety is adopted in structures. A higher safety factor ensures stability to a wider extent but it also increases the material requirement and results in higher construction cost. Moreover, these structures when damaged, gives over estimated repairs.

The distresses mainly damage the core body of the structure and critical points i.e. joints. To repair these is a tedious job especially when the reinforcement arrangement is disturbed.

This reinforcement deformation can be avoided with Shape Memory Alloys (SMAs). For example, take any normal spring and bend its loops in all random direction. When the spring is exposed to heat it will regains its spiral shape. It means that the spring memorizes its original shape and with some heat energy can regain it even after deformation.

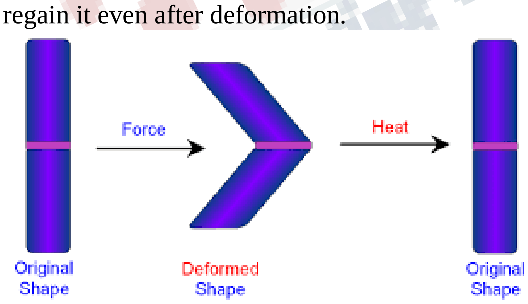

Fig. 7 Regain of original shape by SMA on heating

Similar is the concept of SMAs. A piezoelectric sheet of PVDF (Polyvinylidene fluoride) is laid under the structural elements which have higher probability of deflection. If the element of the structure is under pressure due to deflection then the sheet will generate electrical charges. When these charges are amplified under higher load they convert into heat energy. This heat energy will help SMAs to regain its original shape without causing major distress and could possibly avoid damages. Fig. 7 shows the how a vertical SMAs will regain its original shape after deformation. It has to be noted that heat energy plays a significant role in this process.

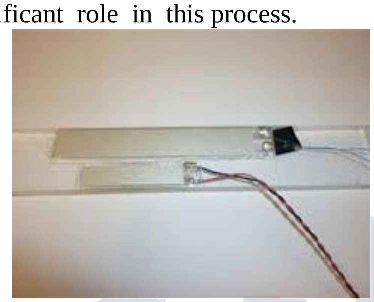

Fig 8 piezoelectric transmitters

Normally it is seen that the shape change phenomenon in any metal results in slight disturbance in the molecular arrangement of the substance at the critical section. However this is not the case of the SMAs. It is designed and trained for the shape change and regain of its original make. These alloys have no change in its strength or durability after the transformation.

SMAs can be used in structures where they will deform to sustain the loads when earthquake strikes. SMAs can prevent a structure from collapse and cause lesser damage. With SMAs repairing would be easier as their wont be major rupture of the steel frame of the structure.

V. CORROSION OF REINFORCEMENT

Normally the reinforcement in a concrete structure is not exposed to the atmosphere and neither to the water above or below ground. But in case of steel structures it is a matter of worry. For structures like steel bridges, trusses, transmission towers, corrosion can cause huge damages. Corrosion de-strengthens the steel and forms a layer of rust around it which increases the cross-sectional area. Conventional methods to control rusting were epoxy coating, anti corrosive materials and so forth. These have proven really effective over years. In case of exposed areas another coating may be required or anti corrosive materials may be too expensive for a specific project. In such cases a thin foil is wrapped around the steel sections. This foil is of non corrodible material like aluminum.

The thin metal foil of non corrodible material is given with a positive potential and the steel with a negative potential. There is a very small gap between the steel surface and the foil. Now when the steel corrodes it expands in cross sectional area as discussed. This is the point where charges attract and the foil automatically becomes an integral part of steel.

Fig. 9 Non corrodible sheet cover

The foil here not only arrests the corrosion but also strengthens the steel by becoming an integral part of the basic metal. It also shares the stresses induced due to corrosion.

CONCLUSION

Smart structures cuts down material cost of the structure. Smart structures monitor the structural health and forecast any danger prior to collapse. This feature also increases the service life of the structure making it more reliable. As we say "prevention is better than cure" smart structures prevent the possible damages, reduce earthquakes intensity and sustain the unexpected load in a better way. With the changing environment and increased frequency of earthquakes smart structures are indeed needs of tomorrow.

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