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RESTORATION POST MARCH 11 2011 EARTHQUAKE

Lian Ching OH

Director, Ground Anchorages Limited (NZ)
Auckland, New Zealand, lianchingoh@yahoo.com.sg

ABSTRACT: The destruction caused by recent earthquakes has indicated that the reconstruction of residential dwelling in particular needs to include the provision of protection against liquefaction and tsunami induced damages while maintaining and improving the protection against ground motion induced damages. This can be achieved by designing a foundation system with the desire engineering properties of high integrity, ductility, bending moment and buoyancy to counter earthquakes and it's after effects.

Key Words: Great East Japan earthquake, earthquake engineering, protection against seismic motions, liquefaction and tsunami, buoyant foundation

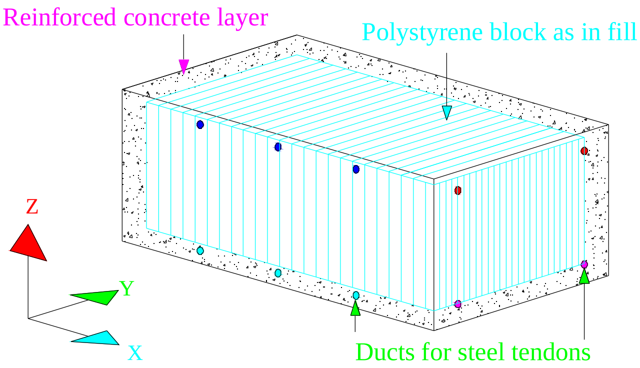
1. INTRODUCTION

The large scale destruction of residential dwellings due to liquefaction and the high fatality caused by tsunami posed formidable challenges to the restoration of the earthquakes affected areas. The need of restoration is inevitable. It is expected to be urgent and massive. The ability to improve the resilience of future dwelling against the forces of earthquakes is crucial for the restoration. This breakthrough is extremely far fetching and has high desirable multiplying effect. It includes the ability to carrying out the restoration on those sites affected without the need to relocate. This as such ensures the restoration can be executed in a prompt and economical manner. These are the most crucial properties of a potential solution for the restoration.

It is indeed ambitious to design a foundation system such that it has the resilience against ground motion, shall remain serviceable during liquefaction including lateral spreading and during tsunami it maintains the very basic function of protecting life by being waterborne. With the progress in engineering particularly geotechnical engineering, the ability to design and create such foundation system is achievable. It is as such high time that segmental construction technique, post tensioning and buoyancy be introduced to create the needed resilience of residential dwelling against the forces of earthquakes. This solution allows the basic function of a dwelling which is to provide shelter and security to be reclaimed back after it was completely destroyed by the recent earthquake.

2. DESIGN CONCEPT

To manage the forces of earthquakes which are randomly propagated, an isotropic three dimensional foundation system is required. The depth of the foundation system shall be large. (A 1.2m depth could be adopted. This is about four times larger than the depth used by conventional raft footing.) The possible dimensions of each segment could be 3mx2mx1.2m deep, 4tons in weight, as shown.



View of reinforced concrete segment in three dimension

Possible dimensions of RC segment of foundation system

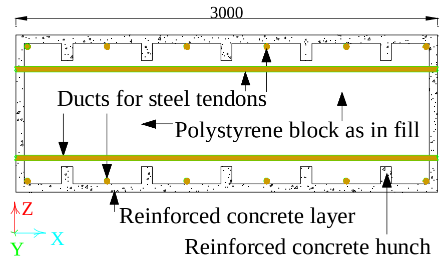


Fig 1-Cross section, X axis

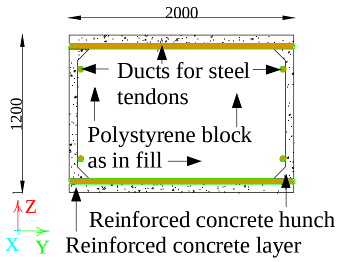


Fig 2-Long section, Y axis

The foundation system must be packed with the desirable properties of high integrity, ductility, bending moment capacity and buoyancy. To design and create these properties segmental construction, post tensioning and buoyancy shall be utilized in total combination. As implied, manageable reinforced concrete (RC) segments are used as the basic building elements. The steel tendons are utilized to bind these segments into a robust integral three dimensional foundation system.

Since RC has high compressive strength, and extremely poor in tensile strength, the steel tendons provide the much needed tensile strength in the foundation system. By installing the steel tendons in both axes of the top and bottom edges of the RC segments, an isotropic three dimensional foundation system is formed.

This arrangement of the steel tendons is efficient in stress transfer. As such the stress in the steel tendons can be kept low to form a compressed foundation system. While it maintains all the RC segments in a compressed state in both axes to minimize the formation of cracks in the RC segments, it maintains the flexibility for the segments to rotate to counter imposed loads.

Since the earthquakes loads are dynamic and as such temporary in nature, the stress in the steel tendons shall return the RC segments back to its original compressed state.

With large depth and the steel tendons located in extreme edges, it creates the large effective lever arm required for the development of high bending moment capacity. Similarly the installation of the steel tendons in both axes creates high torsion capacity.

2.1 Management of ground motion

With depth, the foundation system has large surface area to distribute any axial force imposed on the system. Since stress is inversely proportional to area, this foundation system has the capability to minimize the buildup of axial stress.

Combining the high bending moment and torsion capacity in both axes, it provides the foundation system the three dimensional resilience against ground motions in any direction. The ability of the foundation system to mobilize as one complete integral unit further provides resilience against ground motion induced forces.

Base isolators in the form of compressed spring shall be installed between the foundation and the structure of the dwelling to isolates the dwelling from the force of ground motion. Similarly energy isolators in the form of a combination of lead (metal) and rubber could be incorporated vertically between the segments of the foundation. This is particularly desirable in the longitudinal direction to further facilitate movement and rotation within the foundation system if the need arises.

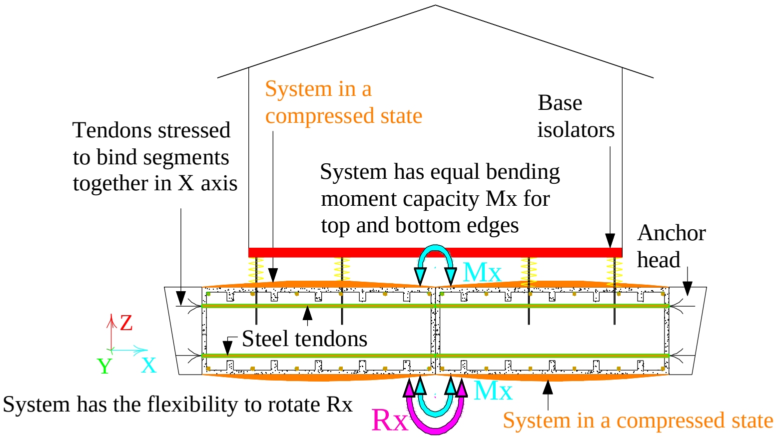


Fig 3- Compressed cross section in X axis

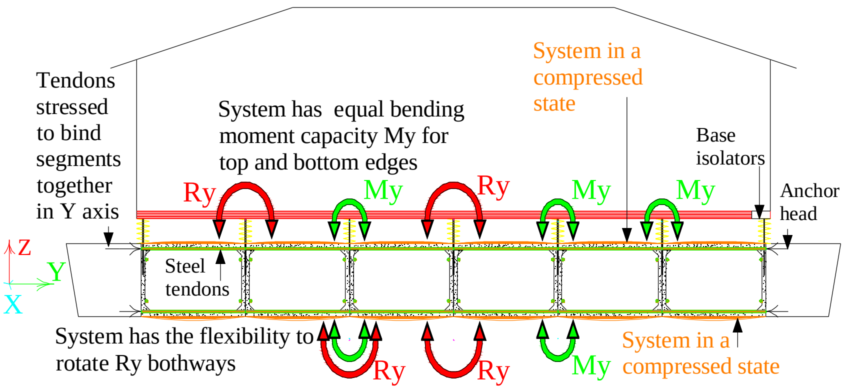


Fig 4- Compressed long section in Y axis

2.2 Management of liquefaction including lateral spreading

As the load bearing capacity of the sub-grade foundation diminishes during liquefaction, the high moment capacity of the foundation system in both axes has the ability to bridge across uneven settlement beneath, thus ensuring the redistribution of the stresses.

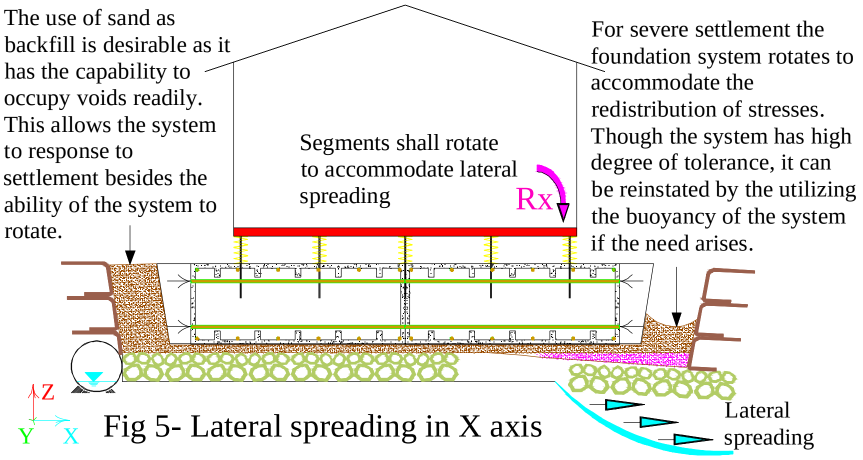


Fig 5- Lateral spreading in X axis

The integrity and the bending moment capacity of the foundation system further ensure that the dwelling remains intact when lateral spreading occurs in any direction.

To minimize self load, the outer reinforced concrete layer of the segment is kept just sufficient to comply with the engineering code of practice which is possibly 60mm in thickness. As the raft segment is constructed cuboids' in shape, it provides stiffness to the segment even though the outer reinforced concrete layer is thin. The segment could be further stiffened by hunching the edges and introducing ribs if required. Each segment shall be cast with a large block of polystyrene embedded to perpetually secure the buoyancy.

Further protection again liquefaction could be derived by incorporating a layer of granular fill (propose minimum 500mm) wrapped with geo-membrane beneath the foundation. The geo-membrane while acts as a separation layer maintaining the granular fill intact during liquefaction, further regulates settlement as well.

The void that is secured in the granular fill by the geo-membrane allows the dissipation of pore water pressure. By incorporating large pipe culverts adjacent to the granular fill the pore water pressure could be dissipated into the atmosphere in a desire direction and location. This provision of dissipating the pore water pressure by filtration minimized the movement of the fine soil particles. This as such minimized settlement once liquefaction subsides.

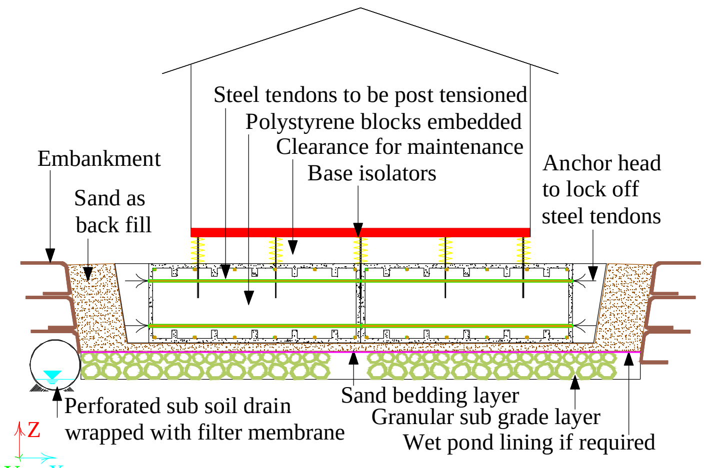


Fig 6- Cross section of granular fill in X axis

2.3 Protection against tsunami

The buoyancy of the foundation system ultimately maintains the most important basic function of protecting life during tsunami as it can act as pontoon to allow the dwelling to be waterborne as one complete integral unit.

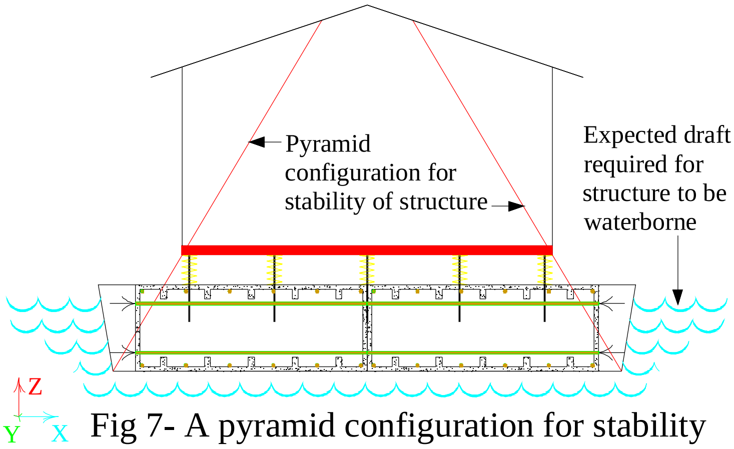


Fig 7- A pyramid configuration for stability

This provides the old and handicapped in particular a chance to survive tsunami. As the magnitude and direction of tsunami are random, it is desirable to secure the stability of the whole structure for turbulent uplift and when waterborne. By configuring the foundation system and the structure of the dwelling in a pyramid configuration it perpetually secure the low centre of gravity, thus ensuring stability at all times.

3. CONSTRUCTION TECHNIQUES

The ease of constructing and achieving the thin outer reinforced concrete layers of the raft segments within close tolerance requires attention. While it ensures the uniform distribution of load in the system, it allows the ease of assembling the raft segments together.

3.1 Preplaced Aggregate Grout for Concreting of raft segments

In order to achieve the close tolerance required, the concreting of the raft segments can be carried out by the “Preplaced Aggregate Grout” method. This construction technique is similar to the grouting operation used in the ground anchor construction, grouting by tremie or pumping grout at the base. The possibility of carrying out the operation in a closed form system allows all the form panels to be completely locked together. As the placing of the grout is carried out under pressure, it is in other words self compacting. Vibration is introduced mainly to overcome the surface tension of the grout.

This as such allows the production of the raft segments with the desired tolerance to be achieved readily with minimum construction skill. Large scale reconstruction with the participation of the local construction communities which is desirable is feasible. The consumption of cement fines however is expected to be twice the amount required as compared to the conventional concrete mix.

3.2 Assembling of the raft buoyant segments

As the raft segments slide together when tensioning is carried out, it is desirable to execute the assembling operation on a layer of sand bedding as leveling is achieved readily. The self compacting property of sand underwater further facilitates maintenance if the need arises. Utilizing the buoyancy of the raft segments for the assembling operation could be a convenient alternative.

Extending this concept further, the cast-in-place technique could be exploited where all the raft segments are cast right at the location where the dwelling is to be finally constructed. These raft segments shall subsequently be floated for the jointing operations. The assembled foundation system shall be lowered into position by dewatering. This minimizes the handling of the raft segments. In situation where machineries are limited and costly particularly in rural and remote areas, this could be an effective option.

3.3 Post tensioning of the raft segments

Besides the vertical location of the steel tendons, the horizontal spacing and thickness of the reinforced concrete segment are the other equally important factors influencing the stressing required.

The spacing of the steel tendons further influences the design of the anchor head that is required for the steel tendons to be locked off.

Since this is an external tendon system, the maintenance and replacement of the steel tendons is feasible. This facility allows the life span of the foundation system to be prolonged. To provide protection and minimize stress relaxation, the steel tendon is to be grouted after stressing. It is desirable that the stressing operation be executed in unison to ensure even stress distribution.

The influence of the stressing can be conspicuously shown in the force diagrams.

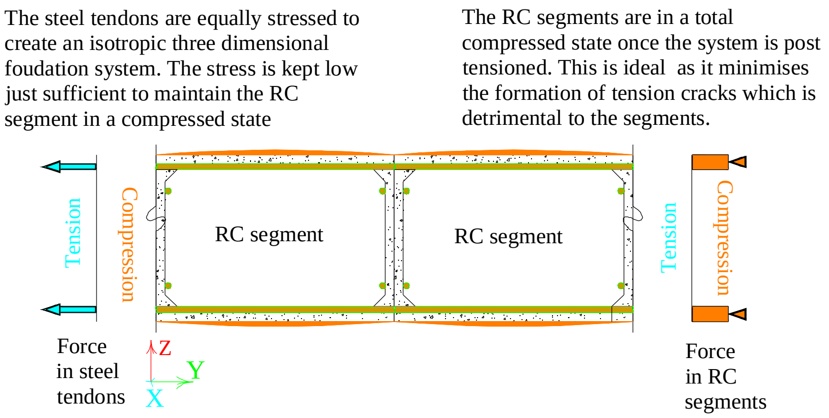


Fig8-Long section, forces in system in post tensioning

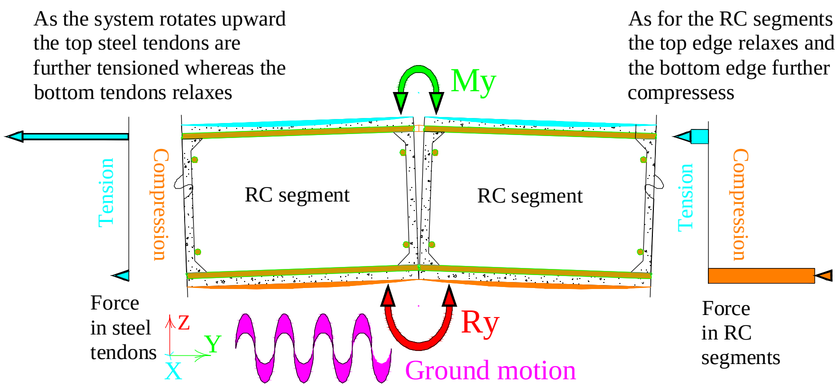


Fig 9-Long section, forces with imposed ground motion load

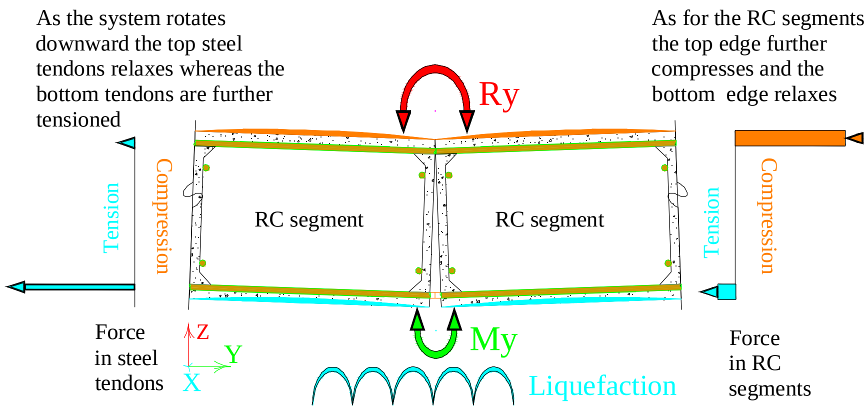


Fig 10-Long section, forces during liquefaction

3.4 Backfill the foundation system with sand

The use of sand to backfill and surround the RC segments are highly recommended. It allows easy maintenance, assists uplift during tsunami and settles responsively to fill up voids during lateral spreading. It could be further capitalized to monitor the presence or the level of water in the foundation system.

4. ADVANTAGES OF THE FOUNDATION SYSTEM

The foundation system as designed and configured allows other benefits to be further derived and exploited. Some of these benefits are as follows:

4.1 Connection of foundation to structure of dwelling

It is expected that the weight ratio of the foundation system to the structure of the dwelling is about 4:1. This allows the connection of the structure to the foundation to be further explored with the possibility of further increasing the integrity and ductility. This is particular desirable if a tsunami shelter is required within the dwelling.

4.2 Soil investigation

The combination of the large depth of the raft foundation system and the broad granular sub grade has virtually eliminated the need of a comprehensive soil investigation. This allows prompt restoration besides the desirable economies.

4.3 Foundation system is based on established engineering principles

Since segmental construction, buoyancy and post tensioning are established engineering principles, the adoption of this concept for the restoration could be well received and accepted. Furthermore the foundation system shall response to any magnitude of tsunami as it utilizes the very basic property of water that is buoyancy.

4.4 Constructability of the foundation system

The configuration of the segment can be capitalized such that its self weight is manageable, the dimension coincides with the spacing of the joist bearer and stable. This flexibility allows the use of smaller and lighter construction equipments.

4.5 Flexibility of the foundation system

The construction concept and the inherent properties of the foundation system provides flexibility toward maintenance, alteration or expansion of the foundation, reinstatement and re-leveling of the dwelling. The method of reinstating a tilted dwelling is as shown below.

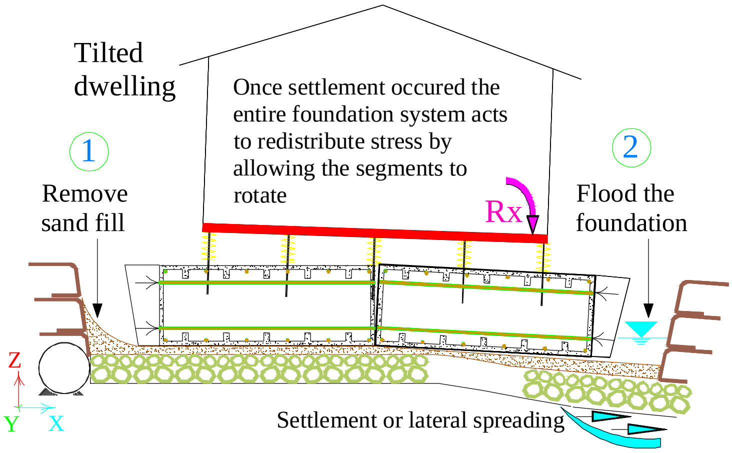


Fig 11a- Remove sand fill and flood the foundation

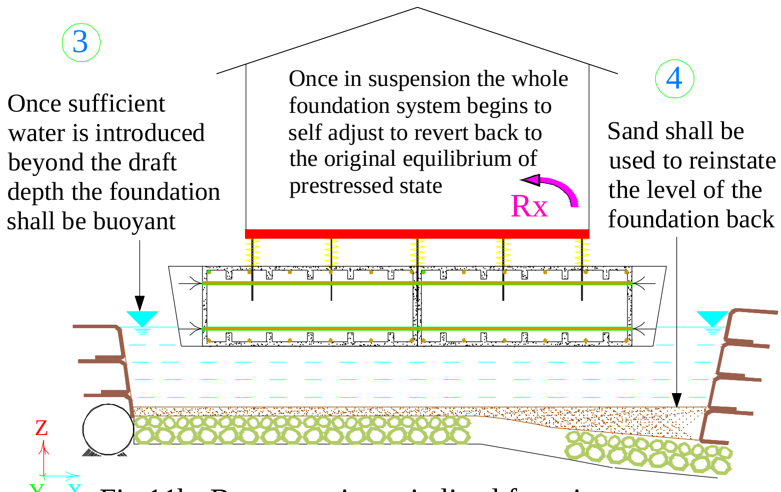


Fig 11b- Buoyancy is capitalized for reinstatement.

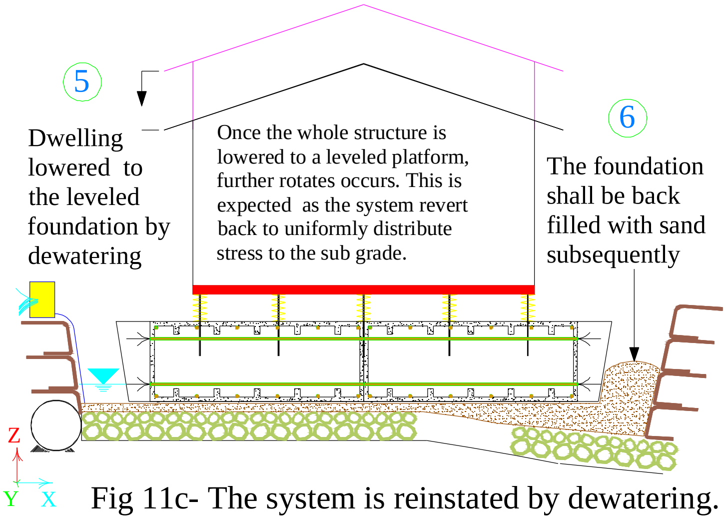


Fig 11c- The system is reinstated by dewatering.

5. DISADVANTAGES OF THE FOUNDATION SYSTEM

The properties of the foundation system have other undesirable effect as well. It is as such appropriate that these disadvantages be highlighted:

5.1 Limitations of the foundation system

It is noted that a 700mm draft of water is sufficient to mobilize the whole system. As such this foundation system needs to be constructed above the required flood level. As the foundation is shallow, the limit of the gradient of the site suitable for the foundation system needs to be specified to avoid building on the slip circle.

5.2 Periodical inspection and maintenance of foundation system

There is a need to carry out periodical inspection and maintenance of the foundation system to ensure that the system maintained its designed properties. This is due to the tendency of corrosion and relaxation of the steel tendons.

5.3 Possible of pounding and collision during uplifting of dwellings

The utilization of buoyancy of the foundation system to manage tsunami for areas with high density of residential dwellings required guidelines on setback as pounding and collision during the uplifting of dwellings could be as disastrous.

6. PREVIOUS RELATED PROJECTS

This presentation is partly based on past experiences in constructing manageable raft buoyant segments by shotcrete technique. Crack inhibiting fibers were incorporated into the dry shotcrete mix.

These segments were bound into desirable configuration and used as pontoon for the construction of dead-man anchor blocks to improve the lateral stability of driven piles which set prematurely. These piles were installed for the restoration of a marina resort damaged during the 2004 Indian Ocean tsunami.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The dead-man anchor blocks were subsequently grouted by tremie under water.

7. CONCLUSIONS

The combination of segmental construction, post tensioning and buoyancy could provide a possible solution for the restoration of particularly residential dwelling in the earthquakes affected areas. With the resilience against earthquakes introduced into the foundation system there is a high chance of carrying out the restoration on the site affected without the needs to relocate.

The benefits of the ability to restore the areas affected are extremely desirable. It allows the restoration to be economically and promptly carried out as identifying and developing new sites would be costly and time consuming. The segmental construction concept allows the use of smaller and lighter construction equipments. It utilizes the basic construction materials. These factors can result in substantial economies. The possibility of the local construction communities participating in the restoration further adds benefit to the system.

From the socio-economic point of view, it allows the fabric of the society to be restored back to normalcy for those who survived besides providing the opportunity for the communities to salvage the history, landmarks and cultures associated with these places. These are desirable for speedy recovery.

As the pressure for land use increases the encroachment of development and population growth into those areas that are in the path of earthquakes and it's after effect is inevitable. This foundation system as such could provide a solution for the values of these lands to be realized.

Most of all, it is hope that this foundation system which provides the solution to protect and minimize future lost of life due to earthquakes could play a major role in the restoration and reconstruction of the Great East Japan back to its former glory.

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