Earthquakes and Lighthouses

1.0 After some investigation the following examples of research and resultant repairs have been obtained on work relating to Earthquakes and Lighthouse Structures.

1.1 FREDERICK INSTITUTE OF TECHNOLOGY – CYPRUS http://www.fit.ac.cy
As part of the European Funded Pharos Project Dr. Milton Domosthenous of Frederick Institute of Technology in Cyprus co-ordinated research into the effect of earthquakes the lighthouses at Paphos in Cyprus. In Paphos, cracks were repaired which occurred after the earthquake of 1995 and at the same time a strengthening scheme was applied by pre-stressing of the concrete slabs. Other damage has been caused through time by the large daily temperature changes and as the result of the actions of moisture there has been corrosion of metal parts and breakdown of internal plaster. Some testing of materials had already been carried out which indicated that the quality of materials used in the structure was high but further testing is required to identify suitable materials for the restoration of the lighthouse. In addition computer modelling used finite analysis to identify possible failure modes due to both temperature and seismic hazards. The seismic hazards based on the Cypriot Seismic Code appeared to be shown to be less than that indicated by the analysis of the data from recent earthquake activity. They results appeared to indicate, as was the case, that the effect of the earthquakes of 1953, 1995 & 1996 would cause considerable damage but no collapse.

1.2 ARISTOTLE UNIVERSITY OF THESSALONIKI – GREECE
Coordinator of EC-Pharos Project. Faculty of Engineering – Laboratory of Building Materials –http://www.auth.gr/
A similar exercise was carried out as part of the European Funded Pharos Project by Prof. Ioanna Papayianni of Aristotle University of Thessaloniki at the Lighthouse of Megalo Emvolo, Aggelochori in Greece. Computer modelling was carried out using the Greek Seismic Code and it was concluded that the lighthouse structure was better equipped to withstand the earthquake and the attached house building which had been added later. It is concluded that the damage to houses would also be significantly worse if damaged areas were not repaired and that to protect the building in future then internal slender walls should also be strengthened.

1.3 At the IALA seminar on the Practical Aspects of Lighthouse Preservation in Gothenburg in August 2005 Tadayoshi Imai presented a paper “Preservation of brick and mortar construction lighthouses” Japan Coast Guard Aids to Navigation, Engineering Division, Maritime Traffic Department, Director of Aids to Navigation Engineering Division, 2-1-3, Kasumiga-seki, Chiyoda-ku, Tokyo
http://www.kaiho.mlit.go.jp/e/index_e.htm

This paper described the preservation of Japanese lighthouses built in the Meiji Era between 1868 to 1912. During the first phase the lighthouses were categorised A to D with A & B being identified as important for historical background, Japanese history, architectural history technology including civil engineering, navigation history, history of lifestyle, local communities etc. whilst those categorised C or D were considered to be of a lesser significant value.
18 lighthouses were categorised A or B and at the time this paper was written three of these had been strengthened to improve their survivability against earthquakes.

The original brick and mortar lighthouses had included copper strips as bed reinforcement to improve their strength but this appears to have been insufficient. The paper goes on to outline three cases where the use of post tensioned steel wires, reinforced concrete and Kevlar strengthening have been used at different locations to best suit the requirements of the individual lighthouse.
Omaezaki Lighthouse - Outline of PC wire lining methods
After V-shaped cut at the angle of 60 degrees is made along the outer wall surface of the tower, 22 pieces of PC steel wires (F100T) are strained tight to create diamond shaped patterns of wires, and “force of tension of approximately 8 t” is applied to each of the wires.
Inubozaki Lighthouse - Outline
Single arrangement of axial reinforcement is employed, and reinforcing steel coated with epoxy resin (deformed member) is used with consideration given to durability. In addition, since the compressive strength of bricks will determine the bearing force of outer walls of the existing lighthouse tower, prestress is applied by arranging hoop PC steel wires in the circumferential direction of the brick walls.
These PC steel wires are fixed within the thickness of 15 cm of reinforcing brick walls. Post-tensioning method is used with VSL (Vorspann System Losinger) method where two PC steel wires are handled as a pair and fastening hardware absorbs tension reaction force.
Shiriyazaki Lighthouse - Introduction of prestress using 10 CFRP tendons (carbon fibre sheet forming tendons)
Applying tension force of 19 tons to each of the CFRP tendons to enhance cracking bearing force of bricks. CFRP tendons are engraved into stone-built ornaments at the upper section of the tower and penetrated into the upper terrace, and predetermined tension force is applied to CFRP tendons on the upper terrace by using hydraulic jacks. Then, steel pipes integrated with tendons (sleeves for restricting expansion) are fastened by nuts on the steel frame cradle which is installed on the upper terrace.
The other ends (fixed ends) of CFRP tendons are anchored into the concrete foundation installed on the lower section of the tower (both by attaching the ends to the concrete and by mechanically fastening them together with anchoring agents)
The bedrock beneath the lower section of the tower is dug and exposed. Then the RC sections installed on the lower section of the tower are integrated with the bedrock by rock bolts which are driven into the bedrock.
Application of CFRP forming materials for enhancing the resistance to bending. This method can mitigate a temporary decline of bearing force after bricks are cracked, exhibiting stable restoring force characteristics.
After the brick surfaces are cleaned, CFRP forming slabs are attached to the brick surfaces of the tower outer walls by mortar-like epoxy resin mixed with silica.
To integrate CFRP forming slabs to the tower section, for the lower parts, CFRP forming slabs are embedded in reinforced concrete-built sections in the lower section of the tower, and for the upper parts, CF sheets are wrapped around over CFRP forming slabs.

1.4 REPAIR OF DAMAGED LIGHTHOUSE AT LITTLE ANDAMAN

Devdas Menon, Professor, Department of Civil Engineering
Indian Institute of Technology Madras http://www.civil.iitm.ac.in/index.html
presented his paper at a seminar in India in April 2007 about repairs to Little

Andaman Lighthouse in the Bay of Bengal after the Tsunami caused significant damage in 2004.

Details of Tower
Reinforced concrete vertical hollow cylinder
Inner diameter of 5.0 m
Outer diameter of 6.2 m at plinth level
Height of 45m above plinth, which is 1m above GL
Shell thickness 600mm at plinth level, reduced in stages to 300mm at the top
Spiral staircase to service room
Entrance porch structure
Well foundation: 7 wells (inner diameter of 3m, outer diameter of 3.9m
Damage observed
Limited to lower portion of the tower (1.3m)
Tilting of tower by 0.5 degree
Spalling of concrete has, especially in N-W location
Concrete damage over a thickness up to 250mm on the outside and 100mm on the inside.
Buckling of steel bars: outer layer has buckled outward and inner layer has buckled inward.
Progressively less damage to N-E & S-W.
Tension failure on S-E side
Evidence of bar corrosion
Summary and Conclusions
The Lighthouse tower at Little Andaman, built in 1980, was damaged by the December 2004 Tsunami.
However, the damage is restricted to the lower portion of the tower; the foundation and upper portions are intact.
A procedure to rehabilitate and strengthen the damaged lighthouse has been proposed and is being implemented at site.

1.5 Repair of damaged lighthouses at Little Basses and Great Basses, Sri Lanka.
After these two lighthouses originally built by the Imperial Lighthouse Service in the 1870's were hit by the Tsunami of December 2004 the lights were extinguished. In co-operation with the Sri Lanka Port Authorities, Trinity House and Northern Lighthouse Board of the UK GLA's sent a team to survey the structures. They reported that the structures had survived the Tsunami with very little damage, presumably helped by the heavy solid bases of the towers specifically designed for wave resistance. However there was severe damage within the lightroom areas and there are proposals being made to modernise the lights and install solar power.

2.0 After an internet search the following organisations or standards were found to have a link to design of buildings with resistance to earthquake damage.

2.1 http://www.architectjaved.com/equake_resistant.html
Various basic articles which give a background to earthquake engineering in terms of cause, effect and solutions.
Archeng Designers,
416-A, 4th Floor, Babukhan Estate
Basheer bagh,

Hyderabad – Andra Pradesh
India

2.2 http://www.bis.org.in/other/quake.htm
Bureau of Indian Standards
IS 1893:1984 Criteria for Earthquake Resistant Design of Structures
IS 1893(Part 1):2002 `Criteria for Earthquake Resistant Design of Structures : Part 1 General provisions and Buildings'
IS 1893(Part 4):2005 `Criteria for Earthquake Resistant Design of Structures: Part 4 Industrial Structures Including Stack Like Structures
IS 4326:1993 Earthquake Resistant Design and Construction of Buildings Code of Practice
IS 13828:1993 Improving Earthquake Resistance of Low Strength Masonry Buildings – Guidelines
IS 13920:1993 Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces – Code of Practice
IS 13935:1993 Repair and Seismic Strengthening of Buildings – Guidelines

2.3 Eurocode 8 - Earthquake

Eurocode 8 explains how to make building and civil engineering structures resistant to earthquakes, though the UK is deemed to have very low seismic risk.

UK status - All parts published as BS codes, final national annex due on 31/07/2008

Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules seismic actions and rules for buildings
Eurocode 8: Design of structures for earthquake resistance – Part 2: Bridges
Eurocode 8: Design of structures for earthquake resistance – Part 3: Strengthening and repair of buildings
Eurocode 8: Design of structures for earthquake resistance – Part 4: Silos, tanks and pipelines
Eurocode 8: Design of structures for earthquake resistance – Part 5: Foundations, retaining structures and geotechnical aspects
Eurocode 8: Design of structures for earthquake resistance – Part 6: Towers, masts and chimneys

2.4 U.S. Army Corps of Engineers – Publications and Manuals for engineering available to general public.
http://www.usace.army.mil/publications/

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WG 2 IALA EEP Committee
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