Analytical Study on Rehabilitation of Critical Electric Power System Components

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BACKGROUND

The overall goal of this study is to improve the resiliency of power system to different modes of hazard. Up to this point, seismic vulnerability of substations, with emphasis on power transformer, has been investigated. It has been shown that using base-isolation is a doable method in improving general response of transformer if some issues are addressed. In the opposite chart, the advantages as well as the potential issues with using base-isolators are summarized.

Investigating the suitability of base-isolation for other types of hazard, that is blast, wind and hurricane is the next step in this research.

Vulnerability and Rehabilitation Strategies for life-lines: A Multi-Hazard Approach

Seismic Vulnerability

Other Hazards: Blast, Wind

Key component in power substations
TRANSFORMER

BASE-ISOLATION
As a viable method to reduce seismic load demand and a doable rehab method
In our studies, the response of transformer mounted on Friction-Pendulum Systems (FPS isolators) is examined

Applications and/or extension of knowledge and experience gained in the seismic field to other hazards

ADVANTAGES of implementing base-isolation

possible ISSUES associated with base-isolation

- Computational Fluid Dynamics: Knowledge gained in studying core vibration can be used for blast load analysis
- Large Deformation Cable Analysis (Catenary and Flexural behavior): Applications to study cable bridges, and transmission lines under serve wind and ice effects
- Blast Load Prediction: Effect of response modification devices on blast load parameters such as incident overpressure, impulse and overpressure duration, reflected overpressure.

Decreasing seismic demand on transformer

Protecting internal components of transformer and consequently reducing any adverse effects on electro-magnetic performance of transformer

Savings in foundation design: concrete slab and anchoring

Adequate SLACK should be provided in cables to accommodate base-isolation displacement

UPLIFTING of BASE-ISOLATOR
The possibility of uplifting is high.
Base-isolator manufacturers have introduced uplift-prevention mechanism

COST-BENEFIT ANALYSIS
INITIAL COST: to be determined more exactly by trial designs for mid-voltage and high-voltage transformers.
However, preliminary analysis indicates the base-isolation is even competitive on initial cost basis.

Current Study:

Sliding-Rocking Response of Stand-free Blocks

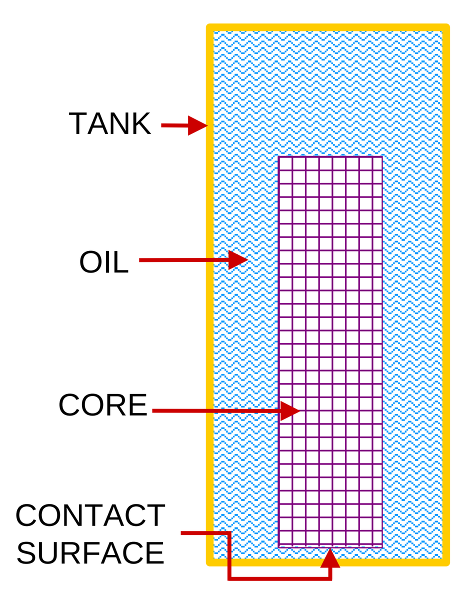
This problem is of interest because it can further highlight the life-cycle benefit of base-isolation. The core of a transformer is a free-standing block, which is immersed in a oil-filled tank. Any form of contact or pounding of the core with the tank can damage insulating structures around the core and peripheral device (shunts), and consequently affect the electro-magnetic performance of the transformer. Thus, quantifying the rocking response of the core and investigating the possibility of uplift as well as the likelihood of overturning is the main objective of current task.

Rocking response of a stand-free block might seem to have some superficial similarities with the oscillation of an inverted pendulum. However, their governing equations is fundamentally different. Gravity is the restoring mechanism for a free-standing block, while spring elasticity provides restoring force for an inverted pendulum. Also, an inherent damping mechanism is associated with rocking motion of blocks. A schematic comparison of a rocking block versus an inverted pendulum is made in figure a (after Makris*).

METHODS

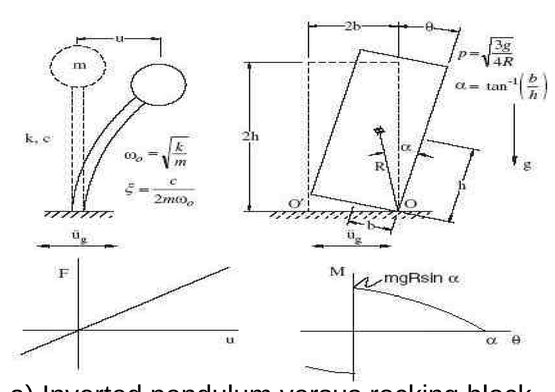
In modeling Rocking-Sliding of Transformer Core following techniques have been used:

- Rigid Block Analysis
Rocking equation has been solved numerically for benchmarking purposes.
- Fluid-Structure Interaction
Core is submerged in oil. Westergaard Added Mass Approach and/or CFD to model oil are used.
- Contact Analysis
Core is not Anchored to the tank. A frictional contact interface is used.

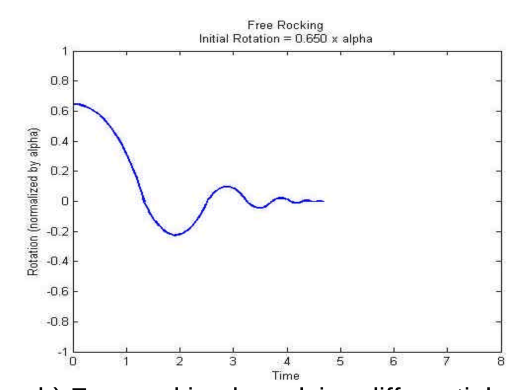


* Makris N. et al., The rocking spectrum and the limitations of practical design methodologies. , Earthquake Engng Struct. Dyn. 2003; 32:265–289

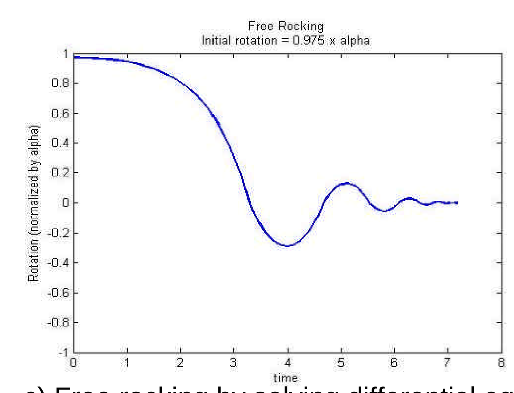
RESULTS



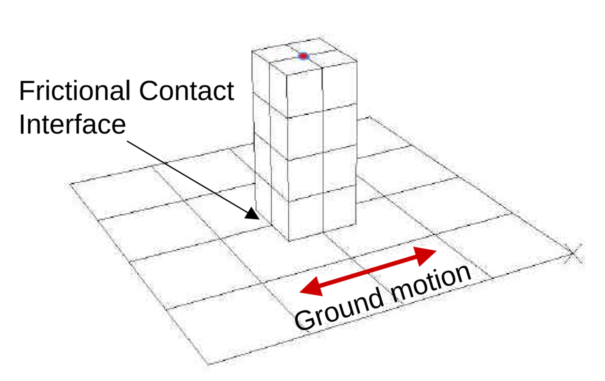
a) Inverted pendulum versus rocking block, after Makris et al. (with a slight correction).



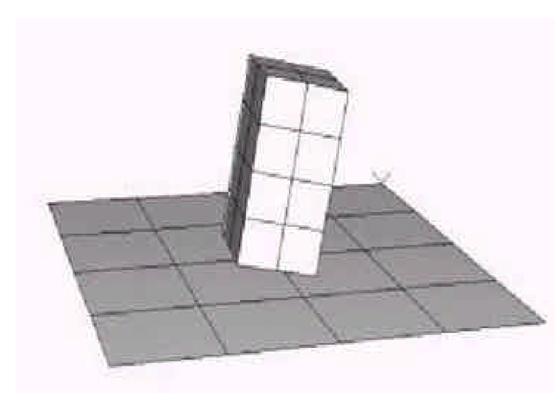
b) Free rocking by solving differential eqn.



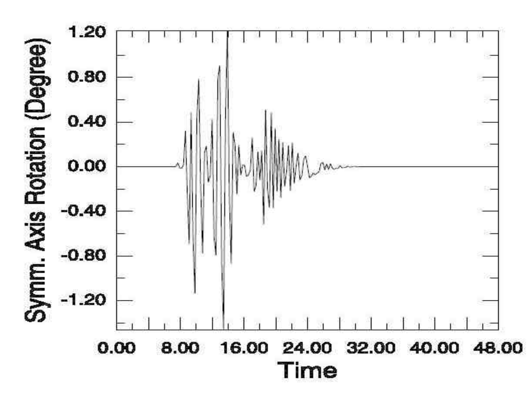
c) Free rocking by solving differential eqn.



d) Finite Element Model



e) Rocking block during uplift



f) Response of a block under Kobe earthquake

CONCLUSIONS

The numerical solution of the rocking motion, briefly discussed, is to verify the finite element model. The finite element model will subsequently be used to examine the rocking response of the core considering both rocking and sliding motions. Furthermore, by using CFD the impact of the oil on dynamic vibration of the core will be investigated. Knowledge gained through advanced CFD analysis can also be applied to quantifying impact of other hazards such as blast load effects on base-isolated transformers.

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