Bull. Ind. Soc. Earthq. Tech., Paper No. 253, Vol 24, No. 2 June 1987, pp. 53–65

# ASEISMIC DESIGN, SAFETY AND STANDARDISED NUCLEAR POWER PLANTS

by

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## ABSTRACT

Important aspects of safety of Nuclear Power Plants with specific reference to earthquake resistent design are covered in the paper.

## INTRODUCTION

For a speedy implementation of the Nuclear power programme, the engineering of the power plants has to be standardised Such a standardisation should cover all aspects of their design, construction, operation and maintenεce. Their ramification on the civil engineering and building work is shown in the figures enclosed. Fig. 1 shows the broad classification of the various elements. Fig. 2 the detailed features covering each element and Fig 3 gives a list of the plant building and structures.

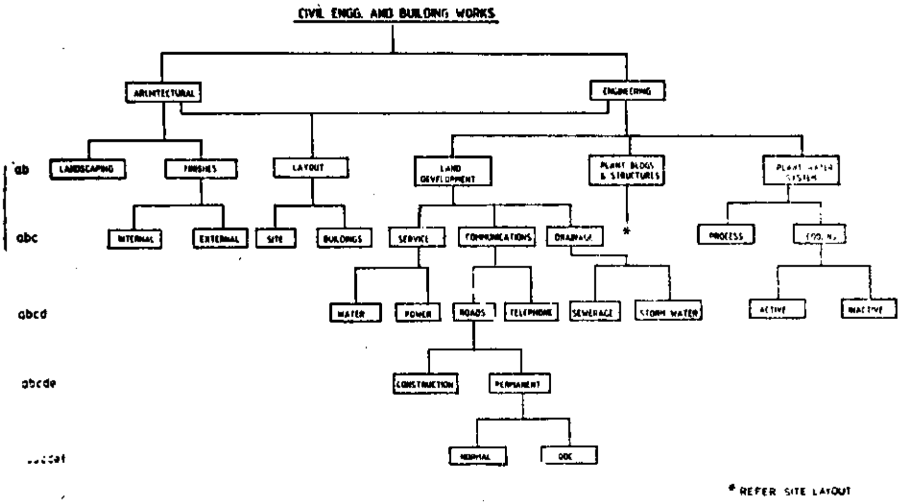


FIG.–1

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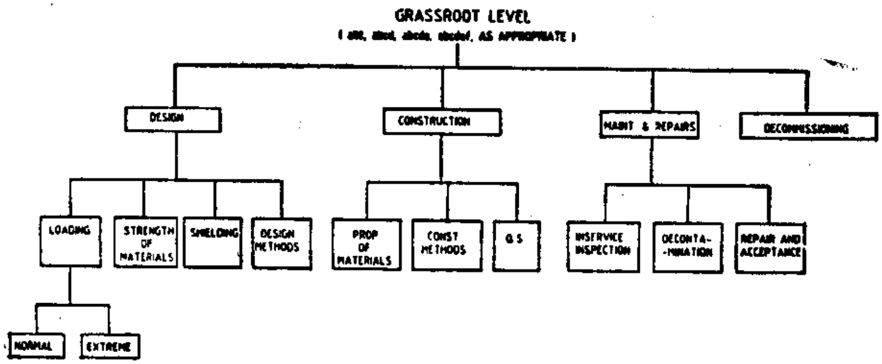



Fig. 2

Nuclear technology has developed through the application of the knowledge and experience in the conventional areas of engineering to this new field. Because of the radiation hazards associated with these facilities, a high performance reliability is demanded of them. Hence even where codes and standards of conventional engineering are applied, they relate mostly to the stringent provisions in them. Radiation safety considerations also add a new dimension. Postulated accident scenarios are examined in depth and form an important part of their design basis. The safety related buildings and structures are designed to resist the accident pressures and temperatures in addition to the other common loading conditions of conventional buildings and structures. Extreme environmental conditions and the effect of man induced impacts on the facility are also accounted for in their design. The design intents are faithfully implemented during their construction through adoption of strict quality control. Engineered safety is thus the product of the loading, design, construction and maintenance aspects considered in the engineering of the plant.

Nuclear technology being a young and fast growing one, a continuous assessment of their safety based on feedback is intrinsic to the installation. It is this inbuilt provision of a constant review of the safety of the plant that has given the civil engineering and building works a prominent place and resulted in developments in this branch of engineering. Blast resistant design, developments in concrete technology, radiation effects on construction materials, earthquake engineering, flood analyses, impact resistant design, inelastic analysis, soil-structure interaction, liquefaction of soils, and the like are areas where the demands made by nuclear technology have led to significant development.

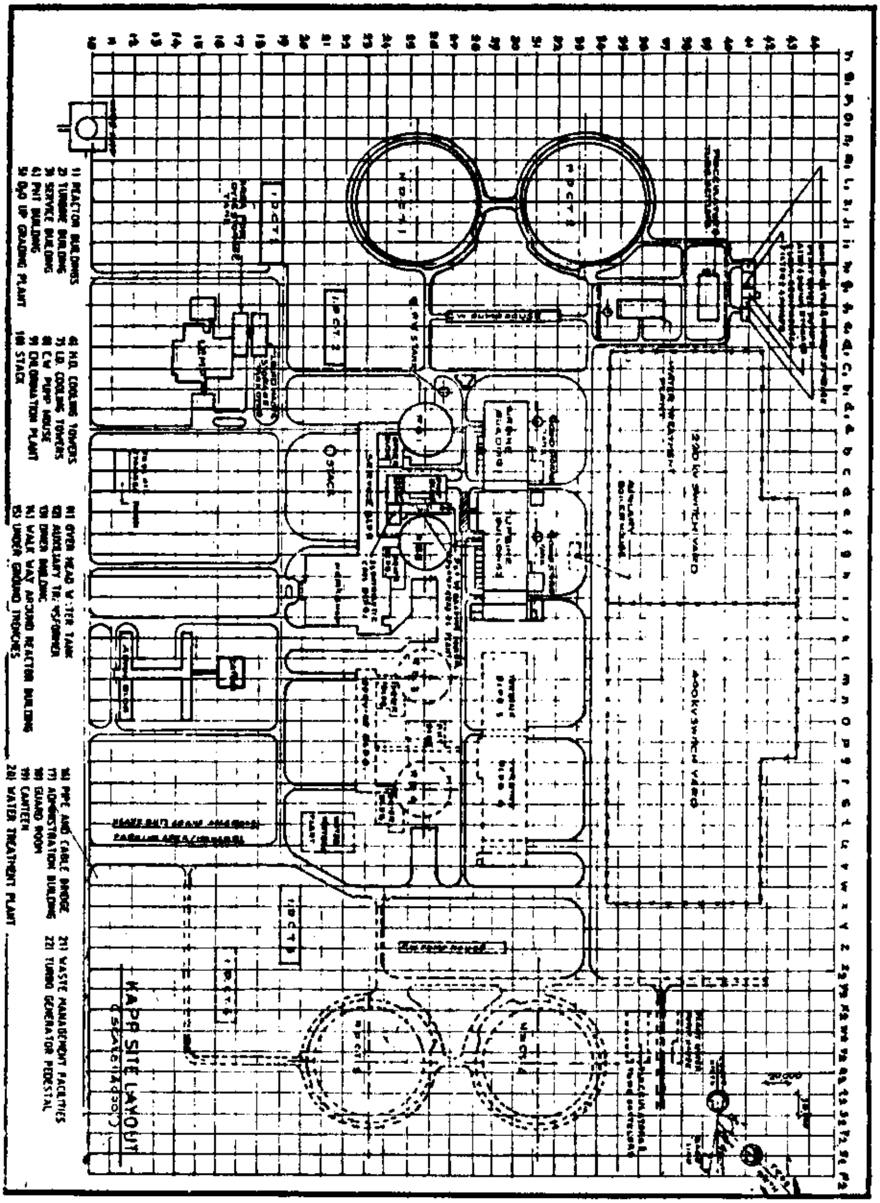



Fig 3

From the stage of the Tarapur Station which was primarily intended to demonstrate the viability of nuclear power in developing countries to the commissioning of Madras Atomic Power Project-2 we now have clearly demonstrated total indigenous capability in the nuclear power industry. Further we have demonstrated that even with the overriding safety concerns in their design, cost of nuclear power compares well with power from conventional thermal units.

## ENGINEERING BASIS

The basis of engineering any facility can be related to codes, guides, recommended practices and case studies. Where the facilities are being engineered for the first time, there is considerable subjectiveness with regard to their design and construction and these are reflected in the case studies. A number of case studies of similar facilities when analysed result in recommended practices. The recommended practices also contain an amount of subjectiveness and the various broad principles are the result of further refinement of the recommended practices. The codes represent a crystallised form of the guides and are the least subjective. They, in fact, should represent the current state of knowledge in the field.

In actual practice, however, because of the constant change in the methods and practices and the functional requirements, the codes are never representative of the current state of knowledge and despite efforts to keep them up to date, they lag behind.

## CODES

The national codes in our country are framed by the Indian Standards Institution. The codes classify Nuclear Power Plants as special structures and call for their examination from first principles on a case by case basis. Therefore, in the design of Nuclear Power Plants even the common environmental loads have to be evaluated abinitio. So far as the extreme value loads are concerned, the codes offer little or no guidance. These loads are currently specified on a probabilistic basis in contrast to the deterministic approach in the I. S. Codes.

A reliable data base is the cornerstone of the probabilistic asseement of design parameters. As in most countries, in India too, this set-back exists, So the estimation of environmental loads is subjective. With the rapidly developing demands on safety, the design of NPPs borders more on 'Art' than on 'Science'. Codes and standards are no gospels but serve as useful guides. Viewed against this back-drop, the operating history of

Nuclear Power plants shows that the excellence in their engineering has greatly contributed to their capacity to pass their re-evaluation during their lifetime. Even a standard design could be rendered non - standard on account of site conditions. These relate primarily to floods foundations and the earthquake environment.

The International Atomic Energy has brought out a number of safety guides relating to siting and design of NPPs which cover the board philosopoy of siting and design and are not reference design handbooks. They presuppose considerable insight on the topic of the guide and are therefore of use to those who are initiated in the topic. They generate a gross picture and are to be implemented consistent with the national codes and practices.

**Foundation Engineering**

From considerations of uncertainty and subjectiveness in design, foundation engineering stands next only to architecture. A well enginereed foundation goes unrecognised but a foundation failure receives wide adverse publicity. Hence, foundation investigations play an important role in NPP siting and the safety of foundations is prime concern in their engineering. The various aspects of foundation investigations are shown in Fig. 4. Current developments in soil-structure interaction and liquefaction of soil under earthquaka are largely the outcome of the demands of Nuclear technology and it will be a long time before these can adequately be covered in codes and standards.

**Structural Engineering :**

Next in importance are the structural engineering aspects of NPPs. This area is reasonably covered by codes and standards for conventional applications, whereas for use on NPPs they still need to be extended. They make a significant impact on cost. As in the case of foundation engineering, the current developments in concrete technology, radiation effects on construction materials, earthquake engineering. impact resistant design and the like are the results of their application to Nuclear technology. This is also an area deficient in codes and standards. Where some exist, they are way behind the current state of the art in these areas.

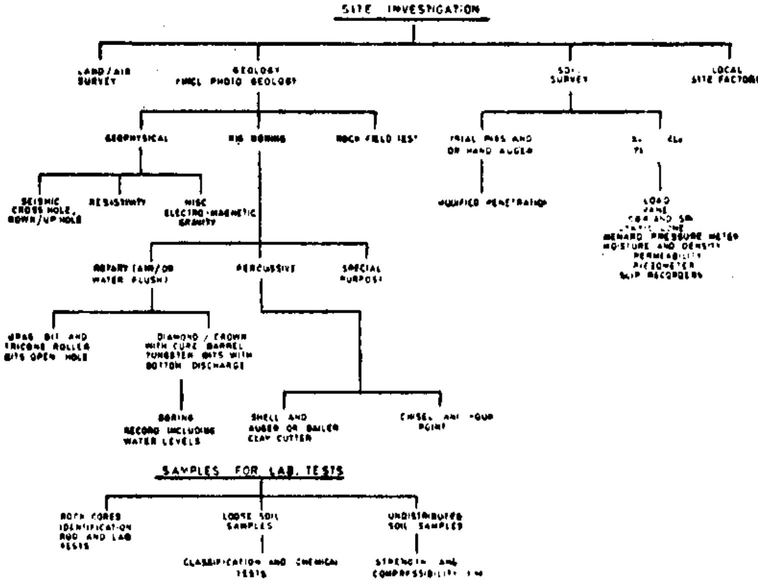



Fig. 4

Earthuuakes form one of the important natural phenomena for which Nuclear Power plants are designed. Currently, engineering solutions are available to resist the vibratory effects of earthquakes, but not for the effects like surface faulting, severe subsidence or ground collapses due to them, Fig, 5 is a flow chart of the steps in earthquake resistant desi gn. Based on the historical data on severe earthquakes, India is divided into five zones, the severity of the earthquake effect increasing withthn number of the zone. Zone V and part of the areas covered in Zone IV on the foot hills of the Himalayas exhibit continuous tectonic movements. The design Basis Earthquakes and the resulting ground [motions are arrived at on a conservative basis consistent with the safety concerns of Nuclear Power plants. The Indian Standard Code I S. 1893 is the national building code on the earthquake resistant design of structures The IAEA safety guide No. 50-SC-S1 "Earthquakes and associated topics in relation to Nuclear Power Plant siting" addresses this aspect.

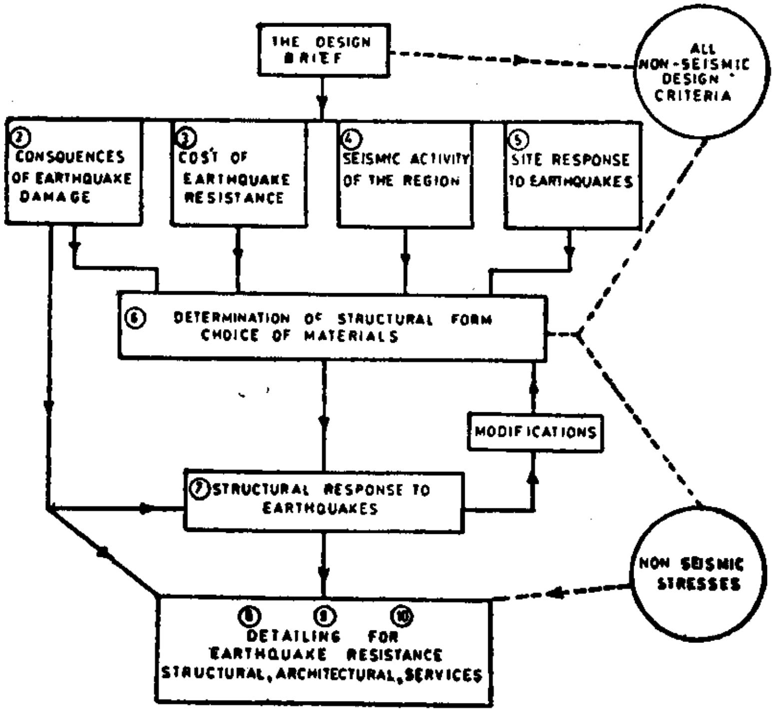
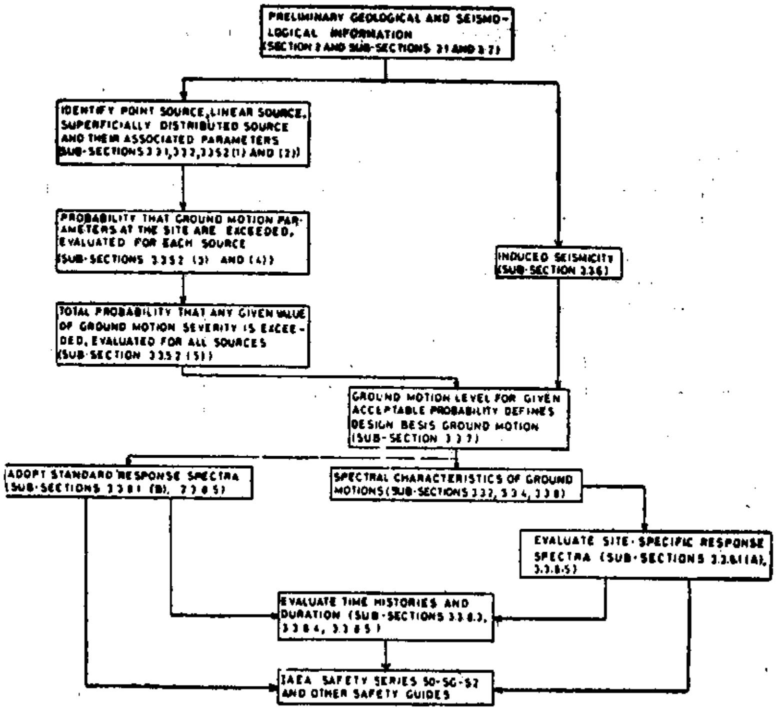



Fig. 5

In the design of buildings and structures, the influence of the site conditions relating to foundations and environmental effects require an amount of compulsory re-engineering at each site. However, in the case of components and systems there is advantage in time and cost in the standardisation of the design requirements. Seismic qualification requires testing facilities and is also engineering manhour intensive. Standardisation wfth an adherence to the IAEA guide on the subject will also help in getting international acceptance to our designs and promote an export potential for them. Flow charts 1 and 2 of Annexure I of the IAEA guide explain rhe steps for evaluating design basis earthquake and associated phenomena. The use of these approaches will lead to specific values of the peak horizontal ground acceleration at each site which will lie in the range of 0.1 to 0.3 g for the $S_2$ level earthquake taking into consideration the effect of high soil cover in alluvial sites. The current approach of maximising the earthquake effects at a site by moving a historical earthquake along a known fault has many assumptions and uncertainties. Both near field and far field earthquakes will need to be taken into account in arriving at the design basis. The structures, systems and components of a nuclear power plant cover a wide range of frequencies and hence the design spectra must be broad banded. For the generation of ground spectra compatible time histories, there is a minimum duration of the shock required for maximising the responses at each frequency compared with the actual values of total and strong motion durations observed during damaging earthquakes. Current international practice limits the duration of strong motion to 10 secs, Spectra compatible time history for one specified damping ( say 5 % of critical ) is a simple and adequate approach and good matching with quick convergence can be accomplished with relative ease.

The standardisation offloor response spectra and compatible time histories can lead to a standardisation of seismic design criteria for components and systems. To arrive at the design spectra statistical averaging of the values is carried out to a prescribed confidence level. Normally a 84 percentile value is currently prescribed in U. S. practice. There is a steady change in the approaches to the engineering of structures, systems and components. Realistic values of damping consistent with the high stress levels in the system and nonlinear analyses can render the designs more cost effective. Provision for the rigid body mode of vibration during earthquakes is an important development in the current approaches to seismic design. The use of base isolators on rocky sites to render the structures flexible, and facilitate whole body movement is a useful approach to minimise earthquake responses of components and systems to low enough levels to permit their standardisation. Avoidance of a problem can also be one of the solutions to it.

Inertial forces can also be reduced by using light weight construction (steel in place of concrete or masonry at heights and structural light weight concrete in place ordinary concrete) and lowering the centre of gravity of support system as much as feasible. In the current classification, Class II compnents and systems are governed by the operability criterion. This is not a safety requirement and it is this criterion which governs the manhours on seismic qualification and in many areas, controls the cost of the components and systems. Some measure of consistency with the current national practices could help in standardisation in all such areas.

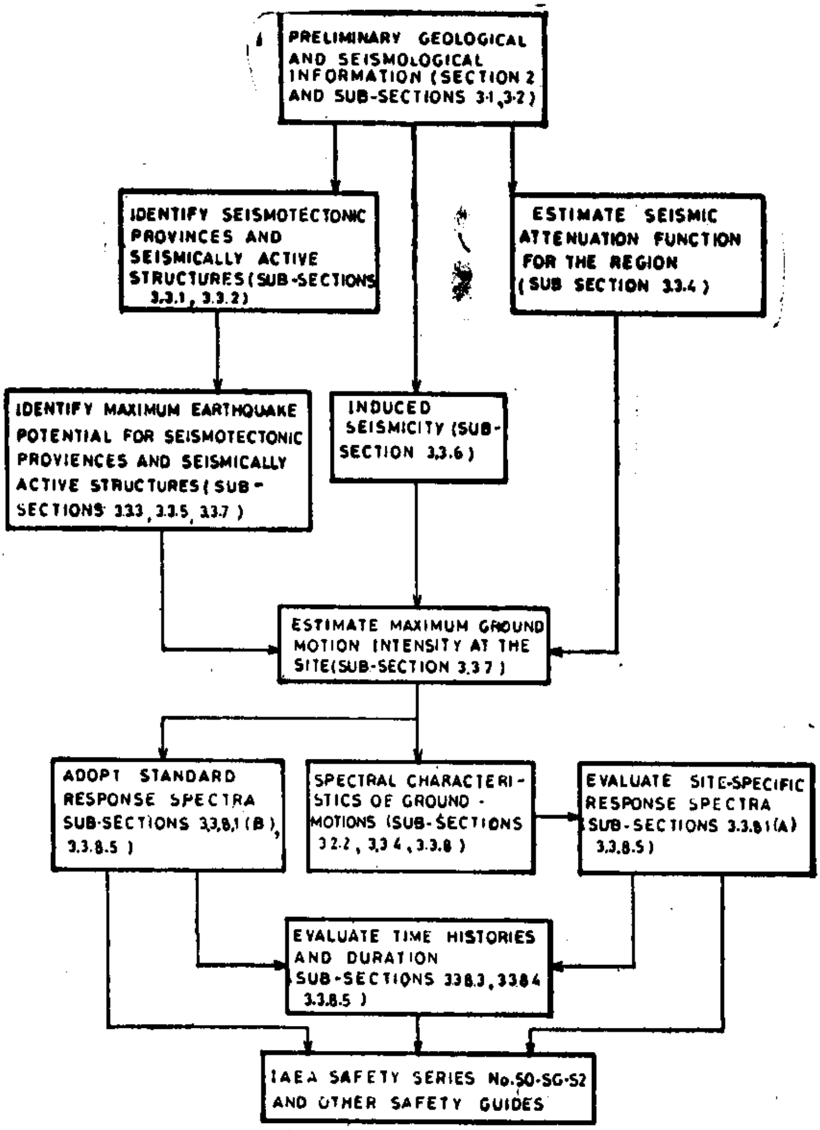



IDENTIFICATION OF VIBRATORY GROUND MOTION
ASSOCIATED WITH EARTHQUAKES
(COMBINED STATISTIC AND SEISMOTECTONIC APPROACH)
FLOW CHART - I

The development efforts necessary for meeting the demands on both analyses and testing of structures, systems and components of pressurised heavy water reactors for seismic qualification are covered in Annexure 1.

**Conclusions**

Each one of the above examples carries the messsage that Nuclear Power plant engineering meks such exacting demands on the current state of our knowled3e in many fields that developmental work is intrinsic to their engineering and will remain so for a log time to come. Safety in the engineering of NPPs is a culture and not merely a concern or a concept. The safety analyses of NPPs encompasses many evolving criteria and requires a check back on existing facilities with appropriate retrofitting to remain operational. Such demands are made with great rigour and the most upto date methods of design and construction need to be adopted to make them cost effective with other conventional sources of power generation. Every branch of engineering has benefitted from the spin off of Nuclear technology and civil engineering is no exception.




IDENTIFICATION OF VIBRATORY GROUND MOTION

ASSOCIATED WITH EARTHQUAKES

(SEISMOTECTONIC APPROACH)

FLOW CHART - II

## ANNEXURE 1

| Serial Number | Problem description |
|---|---|
| 1. | Studies on the detailed examination of the tectonics of sites for NPPs. |
| 2. | Studies on the detailed examination of the seismicity of sites for NPPs. |
| 3. | Basic studies on the specification of site independent response spectra. |
| 4. | Basic studies on the specification of required response spectra for seismic qualification of equipment. |
| 5. | Basic studies under specification of spectra compatible time histories. |
| 6. | Parametric studies to evaluate the effect of embedment in soil-structure interaction. |
| 7. | Basic studies on development of computer software for soil-structure interaction problem. |
| 8. | Studies for evolving a uniform classification of structures, systems and components to exclude mixed classification and starred classification of structures. |
| 9. | Study on two component versus three component motion in case of structures since the present philosophy for the seismic qualification of structures is to consider only two component motion. |
| 10. | Seismic analysis for part of the ventilation system between isolation dampers and penetration seal plates is required. |
| 11. | Dynamic analysis of D20 vapour recovery system for fluctuation consideration. |
| 12. | Studies on the characteristics of snubbers and other displacement controlling support systems with a view to evolving rational specifications for their procurement. |
| 13. | Studies on the specification of testing methods for seismic qualification of active components. |
| 14. | Studies on the results of survey of performance of active components in seismic regions of India. |
| 15. | Immediate procurement of a biaxial shake table capable of generating sinusoidal motion for seismic qualification of components and systems. |
| 16. | Detailed evaluation of Engineering costs on NPPs due to requirements of seismic qualification. |

**Long term requirements :**

17. Basic studies for establishing the correlation between the Richter magnitude and M.M.I. scales of measurement of earthquakes for Indian conditions.
18. Basic studies on the specification of SSE and OBE for NPPs (both deterministic and probabilistic)
19. Fundamental work has to be carried out to develop attenuation laws to suit Indian conditions as most of the correlation in use at present are based on data in Western United States.
20. Basic studies on the specification of effective peak acceleration for NPPs.
21. Basic studies on the development of inelastic design response spectra.
22. Basic studies on evaluation of soil parameters by field and laboratory testing for arriving at soil stiffness and damping to be used in design.
23. Studies on the improvements in the mathematical modelling of structures including substructuring.
24. Experimental and theoretical investigation with correlation between laboratory and site tests are required to assess damping in structures, systems and components.
25. Studies for effect of torsion even in symmetric structures (larger dimension in plan) due to seismic wave.
26. Studies on the improvements in the mathematical modelling of mechanical systems and componants.
27. Studies on the consideration of the effect (such as sloshing and added mass) of liquids on seismic response of the containers.
28. Studies on the development of computer software for the solution of piping response due to multipoint excitation.
29. Studies on the rationalisation of stresses and damping to be adopted in the seismic qualification.
30. Installation of network of strong motion accelerograms to collect earthquake records which could be used for development of design time history and response spectra.
31. Procurement of a programmable three directional shake table facility.
32. Basic studies in the liquefaction potential of NPP sites in India.
33. Cost studies on the remedial measures for design against failure unber liquefaction.

34. Detailed evaluation of direct costs on NPPs due to a change in design seismic level.
35. Procurement and implementation of FLUSH & PLUSH programme for soil structure interation.
36. Studies for estimation of ground movements, assessment of fault capability for estimation of seismic potential of NPP sites. This has to be carried out on a National level on a continuous basis.
37. Basic studies for seismic behaviour of buried structures such as pipes and conduits.