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# Use of an unconventional technique for seismic qualification of equipments

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## Abstract

There is a great deal of equipment in nuclear power stations which is required to withstand predefined levels of earthquakes. Such equipment is generally qualified analytically or experimentally by shake-table tests. However, some equipment is so complicated that an analytical simulation is very difficult. This equipment could also be so large and heavy physically that shake-table testing may not be possible in many cases. One typical example of such equipment is the Diesel Generator (DG) sets of Nuclear Power Plants (NPP's). For functional qualification of such equipment, the use of railway track unevenness to induce stationary random vibrations is being put forward as an economical and conservative alternative. This article also brings out the feasibility of using such a technique for all difficult to model and/or test equipment both in a passive and an active state.

## 1. Introduction

Seismic qualification of equipment, for instance structural integrity qualification as well as operability or functional qualification, is a mandatory requirement to ascertain that the equipment could perform the design function in case of a design basis earthquake. Seismic qualification can be performed either by direct methods like analytical, experimental using shake-table testing or by indirect methods (IAEA, 1992). The analytical methods have the risk of the model not being a true reflection of the structure unless very elaborate modeling techniques are used. Even with an elaborate model, there are many idealizations made which may not be actually realized. The dynamic characteristics of the equipment by experimental means are normally used to verify or help in developing analytical models (IAEA, 1992), but for machinery like the diesel generator sets (DG sets), the complicated constructional features may be difficult to model analytically or to test. The experimental qualification using shake-table testing avoids the modeling deviations and can be performed on the equipment itself or on a full scale model or where appropriate, on a reduced scale model ensuring all similarities between the actual equipment and the scaled down model. Considering the deviations in dynamic performance of a scaled down model, "it is strongly recommended that the equipment itself or a full scale model without any simplification should be

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tested" (IAEA, 1992). But there is a great deal of equipment which is so large in physical size and weight that they are beyond the capacity of the conventional shake-table facilities.

The use of railway track unevenness induced stationary random vibrations is being put forward as an economical and conservative alternative for seismic qualification of equipment. This technique has enough potential to qualify a lot of the equipment of our nuclear power plants both in passive and in operational state. This technique is useful even when the equipment is beyond the capacity of the shake-table and also too complicated for analytical modeling. There is some equipment in a nuclear power plant which needs to be seismically qualified and the DG sets are typical of such. This unconventional technique for seismic qualification is elucidated through the example of DG sets of one of the plants—Narora Atomic Power Plant (NAPP).

## 2. Choice of the test equipment and its functional requirements

One of the broad gauge main line locomotives WDM2 of Indian Railways is fitted with the DG set which have the same diesel engine (16 cylinder, 2400 HP, ALCO/DLW model 251B) as one of our Atomic Power Plants (NAPP). Hence, the DG set of locomotive has been chosen as the test equipment to prove the potential of an unconventional technique for the seismic qualification of equipment.

The DG sets of nuclear power plants cater to the emergency (class III) power supply requirements of the station. Such a requirement warrants these DG sets to be functional in the case of a safe-shutdown earthquake (SSE) level vibration. However, the physical size, weight and the requirement of operability of the engine in a vibratory environment renders the shake-table testing beyond the capability of the normally existing facilities. An analytical qualification procedure, especially for the engine block, is extremely difficult because of the complicated constructional detail which could result in a model too big and too uncertain to be relied upon. Moreover, such an analytical model is likely to be numerically ill-conditioned for solution within acceptable errors. To get over such limitations, this unconventional method using railway track unevenness for functional qualification has been attempted which seems to be an ideal technique for such equipment.

It must be mentioned that the auxiliary components of a DG set of the locomotive for example, fuel oil, jacket cooling, lube oil, inlet/exhaust systems and generator portion have a different layout from the one in the NAPP. For complete qualification of the DG set these auxiliaries have to be qualified separately for the layout applicable to the said plant. Also, these have been qualified analytically but have not been discussed further in this article because its thrust is on the unconventional technique for seismic qualification of equipment.

### 2.1. Seismic requirements

The DG set in NAPP is installed on the prestressed concrete structures of the service building of the reactor for which 5% damping value is reported for SSE level of the earthquake (USNRC, 1973). The DG set requires qualification for the response of this floor on which it is located. But the target for qualification is the floor response spectrum with 4% damping as per the design data supplied for the civil structure. An estimate of the floor spectrum of the excitation seen by the test equipment, for instance the DG set as the locomotive runs over the track during its routine journey on the selected route, could be used to assess the capability of the test equipment to resist SSE level of seismic excitation.

## 3. Details of measurements

Fig. 1 shows the schematic arrangement of a diesel electric locomotive. The diesel engine is attached to the chassis by four foundation bolts—one on either side in the front, above the front wheels, and one on either side in the rear, near the traction generator as shown in the figure.

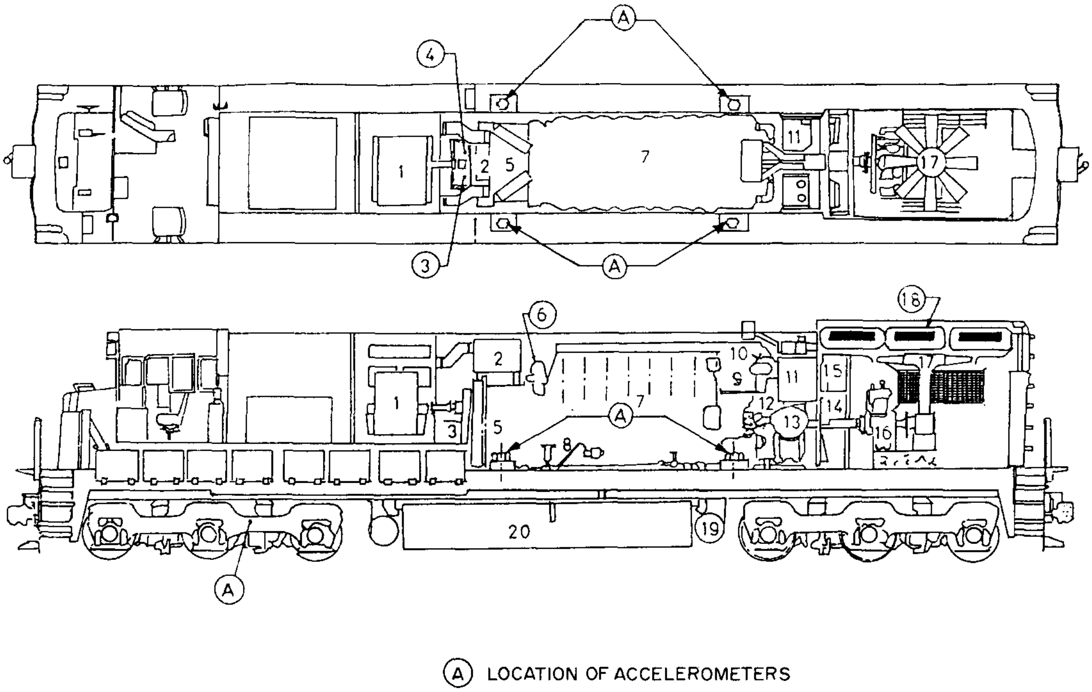

Fig. 1. Schematic of diesel electric locomotive showing measurement locations.

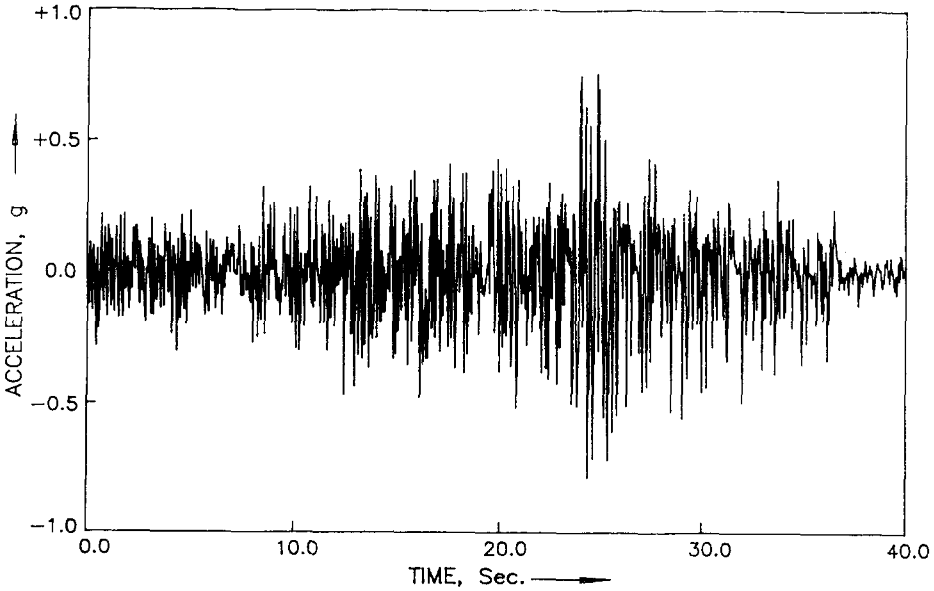

Fig. 2. Typical time-history of vibration experienced by the diesel engine of a locomotive (WDM-2).

Accelerometers were attached to the chassis at the points of bolting to the engine. The sensitive direction of the accelerometers were oriented in the vertical, lateral and longitudinal directions of the locomotive. The signal cables were routed to the driver's cabin where the signals were conditioned and recorded on multi-channel digital tape recorder.

In addition to the diesel engine supports, a measurement of lateral vibration from a point on the axle frame just below the driver's cabin was also recorded.

The signals were collected from the WDM2 locomotive during one of its routine passenger trips on a selected route. The route was selected based on proximity and the presence of many sharp turns which could give adequate horizontal excitation.

## 4. Details of the analysis

The vibrations at the base of the engine caused by railway track unevenness is confirmed to be stationary random by reverse arrangements test and run test (Bendat and Piersol, 1986). Fig. 2 shows typical time–history of the vibration recorded at the base of the engine. The response spectrum (Clough and Penzien, 1993; Bathe and Wilson, 1978) was calculated for this time record. For seismic qualification, the calculated response spectrum should envelope the required response spectrum at the site. If not, the response spectrum is computed for the subsequent time record and the composite response spectrum—the curve of the maximum response of both the response spectra considered together—was compared with the required response spectrum (RRS). The procedure was repeated until the computed response spectrum envelops the required response spectrum or the end of the entire time records of data.

The response spectrum in the vertical and lateral directions were computed when the locomotive was running at a steady speed. So, it would be appropriate to consider them as being excited simultaneously. However, for longitudinal direction, data during starts and stops of the locomotive has also been considered, because of the significant acceleration at these times.

## 5. Results

The results reported here are the envelopes of a large number of response spectra computed for a particular location and direction. The results are presented in Figs. 3–8.

The figures also show the required response spectrum for one of the power station NAPP.

## 6. Comments on the results

The following could be observed from Figs. 3–8:

1. The vertical excitation experienced by the diesel engine at all its supporting points is much higher than the required response spectrum.
2. The horizontal excitation at the rear supports in the lateral direction is much higher than the seismic requirements.
3. The horizontal excitation in the lateral direction at the front supports falls short of the required response spectrum for the particular site upto about a period of 1.0 s. However, the zero period acceleration is much higher than the RRS.
4. The longitudinal excitation is less than the RRS for a small bandwidth around a period of 0.25 s. Also, this longitudinal excitation may not occur simultaneously with the excitations in the vertical and lateral directions.

## 7. Discussion

As can be seen from the various response spectra, the test equipment of the locomotive is subjected to a harsher vibratory environment compared with the seismic forces specified for the nuclear power plant. Even though the excitation in the front supports are less than the RRS, the engine appears to be capable of withstanding the same excitation as in the rear. Actually, the case of excitation only at one end would result in a more severe condition of testing since the same excitation at both the supports would give a rigid body excitation without stressing the engine block. The capability of the internal structures like valves and other actuating links is proven by the huge excitation at one end.

The peak excitation in the lateral and vertical directions occurs at almost the same time. But, the

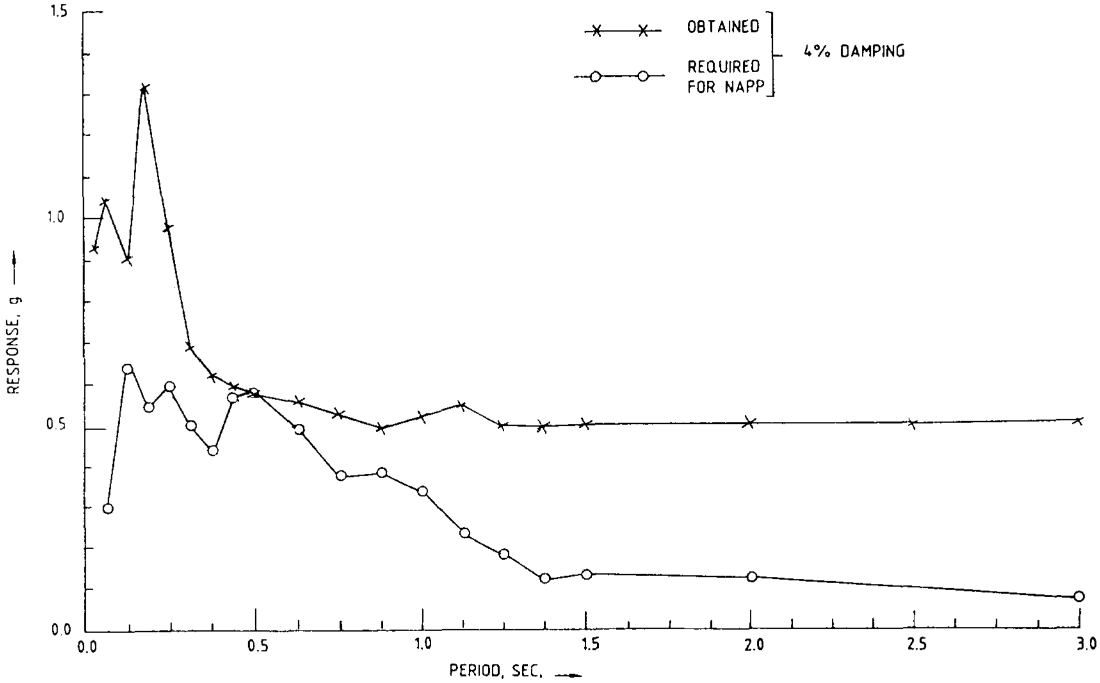

Fig. 3. Response spectrum at the base of diesel engine of the locomotive (front vertical).

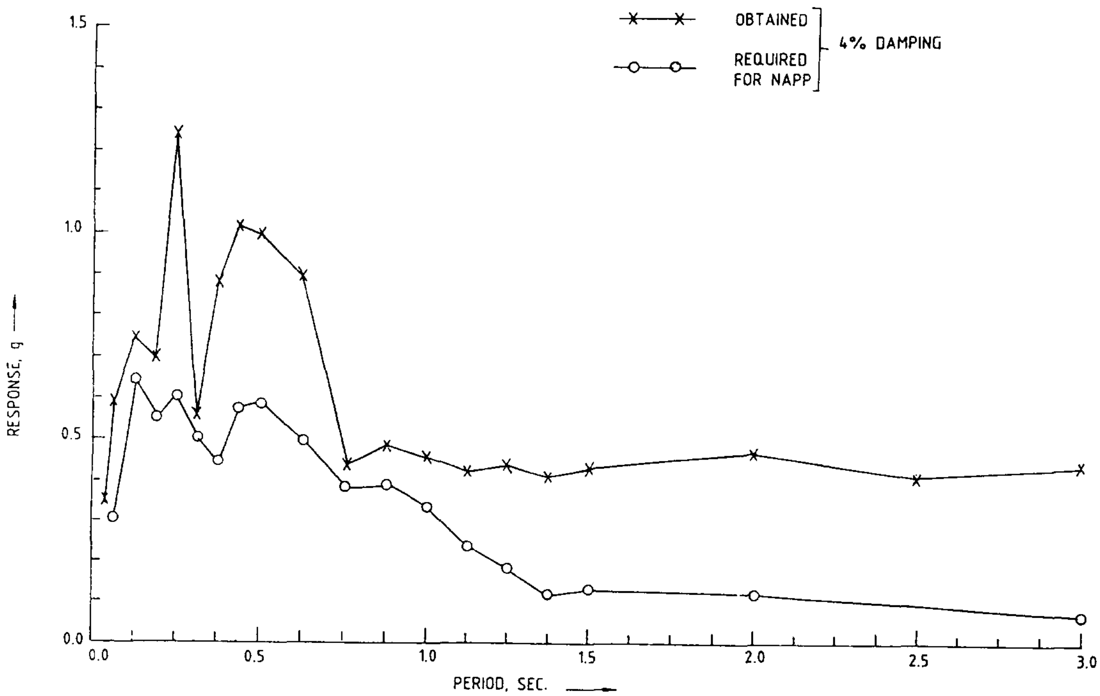

Fig. 4. Response spectrum at the base of diesel engine of the locomotive (rear vertical).

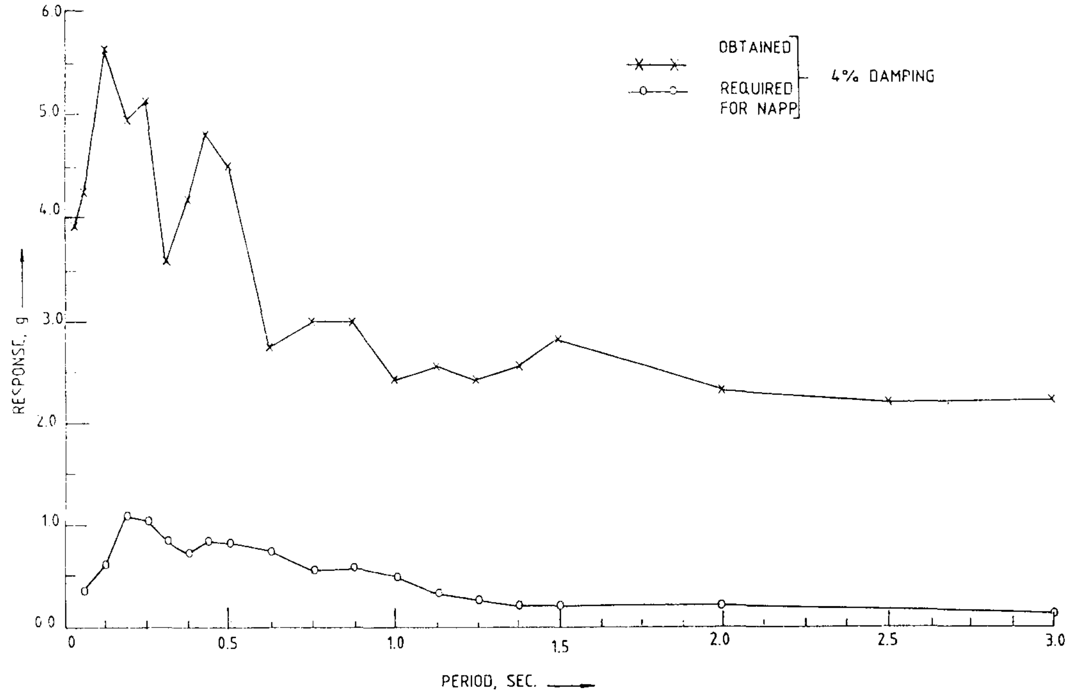

Fig. 5. Response spectrum at the base of diesel engine of the locomotive (rear lateral).

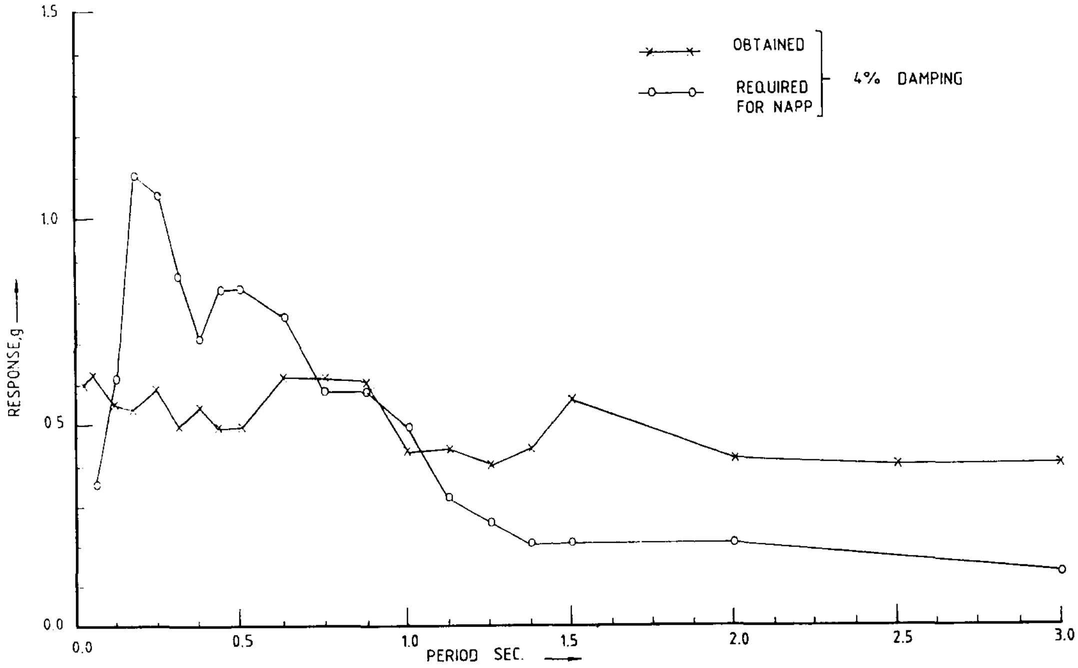

Fig. 6. Response spectrum at the base of diesel engine of the locomotive (front lateral).

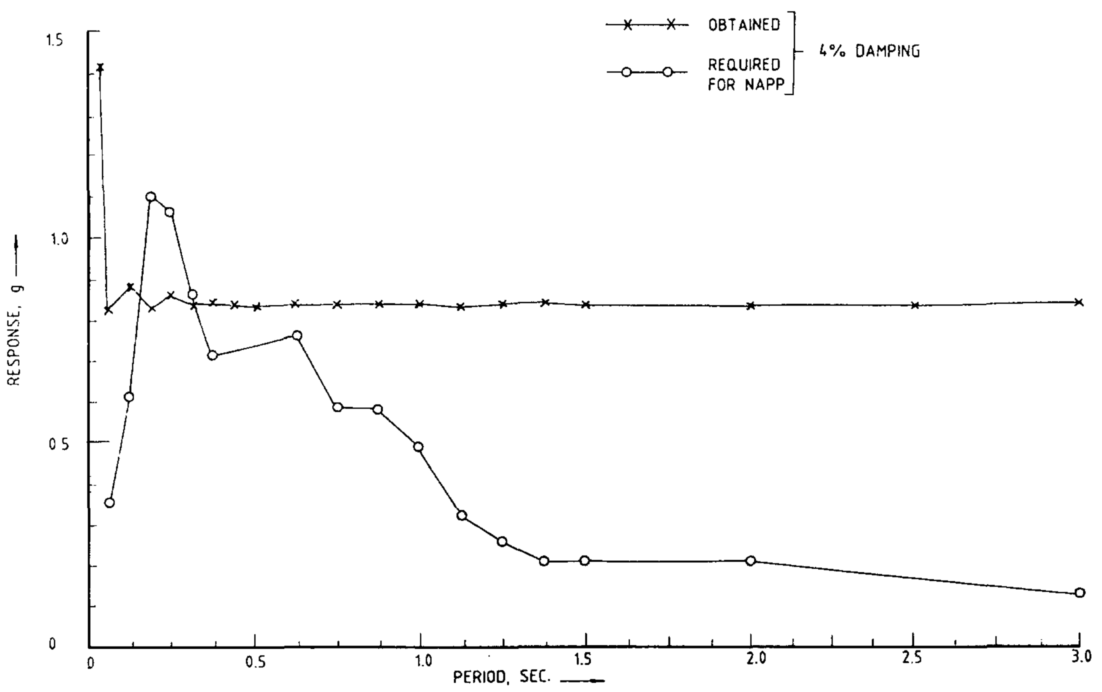

Fig. 7. Response spectrum at the base of diesel engine of the locomotive (longitudinal direction).

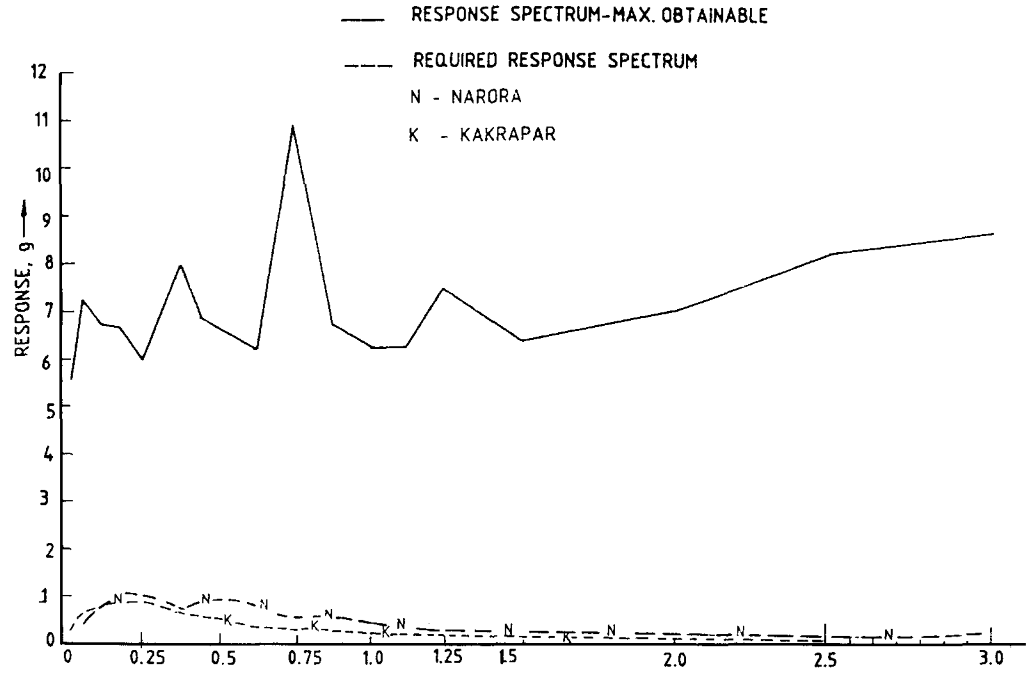

Fig. 8. Usefulness of RLY track unevenness for seismic qualification of equipment.

excitation in the longitudinal direction peaks only during starts and stops of the locomotive. However, considering the constructional feature of the engine, the longitudinal direction can be considered to be rigid and the high ZPA seen in that direction could be considered adequate for seismic qualification.

From Section 6 (1) and (2) it may be justified to deem the engine block of the test equipment such as the DG sets to be seismically qualified for the site in an "active" state. It may also be noted that the engine block can be considered rigid enough to withstand the seismic loads without any damage (Cover and Bohn, 1983), but the important point conveyed through this example is that this technique has enough potential to qualify a great deal of equipment for nuclear power plants for exam-ple, emergency core cooling pumps, fueling machine and so on, even in an active state.

Since the vibrations of the diesel-electric locomotives during its run on rails is stationary random, the qualification of an equipment for transient excitations resulting from an earthquake would be highly conservative.

For the test equipment chosen, DG sets, it is also required to prove that the set could be cold started in SSE level vibration environment (Kawakami et al., 1993; Bell, 1984). Considering the rugged construction of the diesel engine, it could be started in the vibratory environment. It is possible to prove the cold start capability or similar such requirements for any equipments in the vibratory environment by this unconventional technique without any difficulty.

Fig. 8 shows the response spectrum of vibrations on the axle frame. This gives an estimate of the maximum possible excitation that could be achieved on a locomotive. But for obtaining this, the suspension system of the locomotive needs to be stiffened considerably. The figure also shows the required response spectrum of one site, by 'N', and of another, 'K'.

## 8. Conclusions

The above section shows that it would be possible to qualify most equipment in a cheap and conservative manner, by using the track-unevenness-induced vibration of the locomotives. The biggest advantage of the locomotives/wagons is that the equipment could be tested in "active state" often during its transport from manufacturer to the plant site. The drawback of such a method is that even though functional qualification could be easily accomplished, structural dynamic characterization of the equipment may not be easy.

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