DESIGN OF DISTRIBUTION SYSTEMS, VIZ., PIPING, CABLE TRAYS AND DUCTING

S.M. Ingole[1], Faisal Dastageer[1], Anshuman Singh[1], Rahul Mittal[1], Santosh Khandave[1], B. Santosh Kumar[1], Vijay Chaudhry[1], Rajesh Mishra[2], U.P. Singh[1], S.D. Bhawsar[1], R.N. Bhawal[1], A.G. Chhatre[1]
[1]Nuclear Power Corporation of India Ltd., Mumbai-400094, INDIA
[2]Bhabha Atomic Research Center, Mumbai-400085, INDIA

E-mail of corresponding author: smingole@npcil.co.in

ABSTRACT:

For seismic qualification of piping system lot of efforts are put up by performing time history analysis, response spectrum analysis or multi support excitation analysis using the free field time history/response spectra or floor response spectra to find out the inertial forces and the resultant stresses in the piping components and the supports.

With the recorded ground motion available for Stable Continental Region (SCR) and Active Tectonic Region (ATR), it is quite evident now that the spectral shapes for SCR and ATR site are quite different in terms of frequency content. The hard rock spectra peak between frequencies 5-8 Hz for ATR, whereas for SCR, it peak between 10-25 Hz. If there is soil cover over the rock, then the spectral frequencies shift further to a lower frequency and the spectra gets amplified. The spectra for soft soil peaks between 2-5 Hz.

As done in other parts of the world in the past, the Nuclear Power Plants (NNPs) in India except NAPS which in ATR viz., TAPS, RAPS, MAPS, KAPS, Kaiga and Kudankulum are in the Stable continental region i.e. peninsular India on hard rock have been designed for ground motion of soft or medium rock of ATR. This is so because in the past, earthquake records were available from ATR of Western USA with shear wave velocity (Vs30) of about 200 m/sec in soil, 760 m/sec for medium rock and a maximum of 1000 m/sec for hard rock site in general, whereas in SCR, the hard rock site have a shear wave velocity (Vs30) of 1500 m/sec and even upto 2900 m/sec.

In general, the supports for the piping in conventional industries are rod hanger or spring hanger type. The piping and cable trays supported with rod hangers have frequency less than 1 Hz and should experience an acceleration of about 0.03g on hard rock site; however, the spectra on soft soil used for the design of piping necessitated the piping and cable trays to meet an acceleration of 0.3g instead of 0.03g. As the rod hangers could not meet the qualification requirement for this acceleration, the supports were changed to angle and channel sections, thereby increasing their stiffness & frequency and being in ascending part of the spectra, resulted in attracting more acceleration, requiring further increase in the support section size, till the frequency of the system went in the descending part of the response spectra. Presently, this process of increased support stiffness is being reverted back to meet the low accelerations in low frequency region of the ground motion spectrum of SCR by using flexible supports or by having supports at 3 to 4 dead weight spans.

Large unrealistic conservative floor response spectra is another reason for conservative rigid supports or snubbers on piping. The analytically calculated floor response spectra for Kashiwazaki-Kariwa(on soft soil) and for Shika (on hard rock) Nuclear Power Plants (NPPs) in Japan are higher in comparison to the recorded values. The aim of putting the seismic instruments in a NPP buildings is to benchmark the analytical calculations to remove the areas of un-conservatism if any, but the aim is also to remove the areas of too much conservatism as well. The supports also became rigid due to lower values of damping used for piping analysis and to use floor response spectra instead of amplified floor motion due to flexible supports.

The earthquake experience based data on piping, piping, cable tray & ducting systems have been collected from the industries which have witnessed earthquakes of Koyna (1967, 6.5M), Bhuj (2001,7.6 M) & Muzaffarabad (2005,7.6 M). Out of hundreds of kilometers of piping, failues in only three piping have been observed, which were not due to inertial forces, but due to seismic anchor movement to a rigid piping and due to movement of big equipment/piping connected to small diameter rigid piping.

From the database of failures in corroded piping during Kobe, Japan earthquake, there is a possibility of failure of piping due to inertial load which may be due to reduction in load carrying capacity of the piping due to thickness reduction because of corrosion which can be tackled by regular in-service-inspection and then

by replacement, if the thickness goes below allowable limit. As observed from the general industries in India and also from Kashiwazaki Kariwa NPPs & Shika NPPs in Japan, piping have survived with both rigid supports as well as with flexible rod hanger type supports. Flexible piping can withstand SAM with comfortable margin and will have low thermal stresses. Hence, it is better to have a flexible piping with rod hangers rather than rigid piping with closed spaced supports with U clamps. As brought out above, based on the feed back from the experience based data, there is a need to rethink and correct ourselves in our design methodologies.

Similar is the case of cable tray and ducting, in the past, in order to attract lesser accelerations, the supporting system have been made rigid by increasing their stiffnesses, thus increasing their frequency and going in the descending part of the response spectrum where the acceleration are lower for the spectra in soft soil,. However, based on the experience based data from industries which witnessed Koyna (1967, 6.5M) and Bhuj (2001,7.6 M) earthquakes, the cable trays and ducting were generally supported by hanger rods i.e flexible supports and have survived the earthquake.

The paper brings out the insight into the support design of the piping, cable tray and ducting system in view of the considerations brought out above. Number of studies have been carried out to study the effect of hard rock and soft soil spectra on piping support span, amplification in spectral value in low frequency region, floor response spectra and floor displacements for building located on hard rock and soft soil site. The paper also brings out the experience based data on piping, cable trays and ducting system from the industries in India which have witnessed Koyna (1967, 6.5M), Bhuj (2001,7.6 M) & Muzaffarabad (2005,7.6 M) earthquakes.

Key Words : Active Tectonic Region, Stable Continental Region, Floor Spectra, Seismic Anchor Movement

INTRODUCTION

The earthquake experience based data on piping, cable tray & ducting system have been collected from the industries which have witnessed earthquakes of Koyna (1967, 6.5M), Bhuj (2001,7.6 M) & Muzaffarabad (2005,7.6 M). Out of hundreds of kilometers of piping, only three failures in piping have been observed which were not due to inertial loads, but due to Seismic Anchor Movement (SAM) or due to movement of big equipment/piping connected to rigid small diameter piping.

In general, the supports for the piping in conventional industries are of rod hanger or spring hanger type, which made the piping flexible. As the pipe with a rod hanger type support is like a pendulum, which can not be modeled in Finite Element Method (FEM) used for analysis, required fixing of upper end of the support. This has resulted in increased frequency, attracting more acceleration which further resulted in increased support & piping stresses leading to increase in support section & closer support span, till the piping frequency was shifted in descending region of response spectra.

As observed from the general industries in India and also from Kashiwazaki-Kariwa & Shika NPPs in Japan, piping have survived with both rigid supports as well as with flexible rod hanger type supports. Flexible piping can withstand SAM with comfortable margin and at the same time will have low thermal stresses. Hence, instrad of a rigid piping having closely spaced supports with U clamps , it is better to have a flexible piping rather than.

With the recorded ground motion available for Stable Continental Region (SCR) and Active Tectonic Region (ATR), it is quite evident now that the spectral shapes for SCR and ATR site are quite different in terms of frequency content. The hard rock spectra peak between frequencies 5-8 Hz for ATR, whereas for SCR, it peak between 10-25 Hz. If there is soil cover over the rock, then the spectral frequencies shift further to a lower frequency and the spectra get amplified. The spectra for soft soil peak between 2-5 Hz. Based on the soil type, being hard rock or soft soil or in SCR or in ATR in which the industry with the distribution system is located, the support span for the distribution system will be different.

DIFFERENCE IN THE SPECTRAL SHAPE FOR THE EARTHQUAKE RECORDS ON HARD ROCK AND SOFT SOIL

It is important to know the earthquake ground motion to which the building with the distribution system will be subjected. This is significant, in view of different spectral frequency content of the ground motion for the Stable Continental Region (SCR) and the Active Tectonic Region (ATR). The hard rock spectra peak between frequencies 5 to 8 Hz in case of ATR and peak between frequencies 10 to 25 Hz in SCR. In case, there is a soil over the rock, the spectra further shifts to lower frequency and the spectra get amplified. The

spectra peak between 2 to 5 Hz in case of soft soil. For this varying spectral shape depending on the site type, the accelerations to which the distribution system will be subjected will be different and this will lead to different support span based on the soil type and the plant being in ATR or in SCR.

A study has been carried out on the recorded earthquake in Bhuj region of India (SCR) to understand the ground motion on hard rock as well as on soft soil site. A comparison of the response spectra on the hard rock and the soft rock site for Bhuj earthquake (2007) of 4.6 magnitude is shown in Figure-1. It can be seen that the frequency contents for both hard rock and soft soil site vary for the same magnitude earthquake. The spectral peak for the soft soil site spectra lies between 3-4 Hz, while it lies between 20-25 Hz for hard rock site.

Similarly, the frequency content of the spectra on hard rock also varies from ATR to SCR. A comparison of spectra derived for a site having shear wave velocity (Vs30) of 760 m/sec from Atkinson & Boore (2006) attenuation correlation for Eastern Northern (EN) USA (Stable continental region) [Ref-1] and Boore & Atkinson (2008) correlation for Western USA (Active tectonic region) [Ref-2] is shown in Figure-2 for an earthquake of magnitude 6.0 at an epicentral distance of 30 km with a depth of focus of 15km. For Western USA, the spectral peak occurs between 5-6 Hz with lower PGA, whereas for EN USA, the spectral peak shifts to 15 Hz with corresponding higher PGA.

The design philosophy for piping support span will be different depending on the site condition i.e. whether the site is on soft soil or on hard rock or whether the site is in ATR or in SCR.

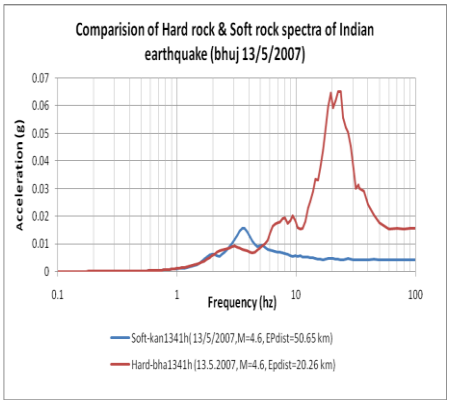

Fig 1 : Comparison of hard rock & soft rock spectra for Bhuj 2007 earthquake of 4.6 Magnitude

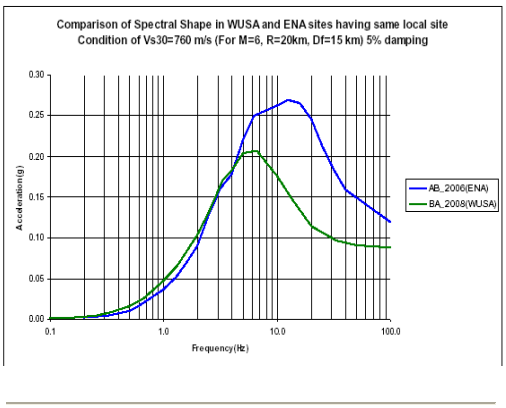

Fig.2: Comparison of spectral shape for WNA(Active Tectonic) and ENA (Stable continental) Site

ANALYSIS OF A REPRESENTATIVE BUILDING OF NPP TO STUDY AMPLIFICATION OF GROUND MOTION IN LOW FREQUENCY REGION, FLOOR SPECTRAL ACCELERATION, GROUND DISPLACEMENT AND RELATIVE FLOOR DISPLACEMENT FOR HARD ROCK AND SOFT SOIL

No amplification of ground motion in low frequency region up to 1.0 Hz

The major input that has been used in the concept of flexible supports for flexible piping, ducting and cable tray like linear systems is that the earthquake accelerations do not amplify in the low frequency region up to 1.0 Hz for hard rock and soft soil ground motion i.e. the ground motion remains same, whether it is at free field or at higher elevation of a structure [Ref-3].

The effect of hard rock and soft soil condition on the floor response spectra and the floor displacement, a representative building of NPP having floors on 17, 24, 34, 47, 70 and 110 feet has been analysed. The soil type for soil-structure interaction is accounted by modeling the soil by soil springs. The building has been analyzed for hard rock & soft soil condition i.e. for hard rock site, the soil springs corresponding to hard rock are used and for soft soil site, the soil springs corresponding to soft soil are used. For calculation of spring constants, ASCE 4-98 has been used with Vs30 of 2900 m/sec and 200 m/sec for hard rock and soft soil respectively [Ref- 4].

Study on floor response spectra for hard rock and soft soil

The free field spectra and the floor spectra up to 70.0 ft elevation for a representative building of NPP on hard rock and on soft soil are shown in Figures-3 & 4 resp. For hard rock site, it is seen that, there is no amplification in the ground motion even up to 2.0 Hz frequency, irrespective of the floor elevation, whereas for soft soil site, there is no amplification in the floor motion for frequency up to 0.8 Hz, irrespective of the floor elevation.

From the figures 3 & 4, it is seen that the maximum spectral acceleration and corresponding spectral frequency for hard rock are 3.25g at 6 Hz frequency and for soft soil, 1.9g at 2.1 Hz respectively. The corresponding free field ground accelerations are 0.55g at 6 Hz and 0.52g at 2.1 Hz for hard rock & soft soil respectively. At around 1.5 Hz frequency (which generally corresponds to flexible piping), the spectral accelerations are 0.25g & 1.0g for hard rock and soft soil respectively and at 6 Hz (which corresponds to rigid piping frequency), the spectral accelerations are 3.25g and 0.6g for hard rock and soft soil respectively. The floor spectra for hard rock do not get flattened even after 33 Hz frequency, unlike soft soil spectra.

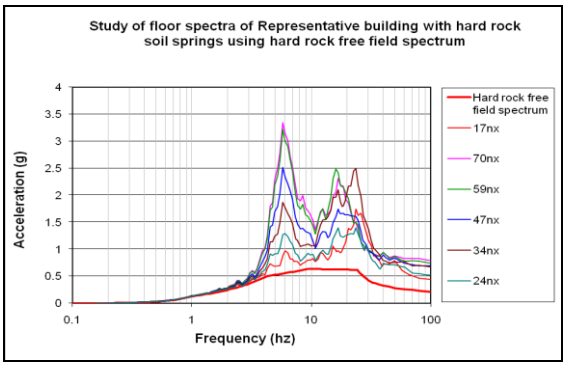

Fig.3: Floor spectra at different floor of building with hard rock spectra

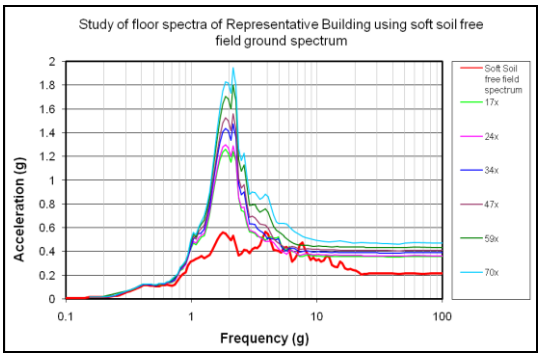

Fig.4: Floor spectra at different floor of building with soft soil spectra

Study of ground displacement and relative displacement between various floors for hard rock & soft soil

The piping, cable trays and ducts, if supported by hanger rods is like a pendulum and the fundamental frequency for this pendulum system comes in the region of 1 Hz or less than 1 Hz, such system is referred as flexible system. The flexible system has a characteristic of attracting less ground acceleration, but will experience large displacement. Hence, while designing such flexible system viz., piping, ducting and cable trays, one should have a knowledge of the ground motion displacement as well as the amplified displacements at various floor elevations of the civil structure on which they are supported.

The relative displacements at various floors of a representative building of NPP for hard rock spectra and soft soil are shown in Figure 5 and 6 respectively.

The analysis results show that at top most floor elevation corresponding to 110 ft elevation, the maximum relative displacement for hard rock site is only 0.58 cm whereas for soft soil site, it is 4.45 cm. Similarly, for a system going from 57 ft floor to 70ft floor, it will be subjected to Seismic Anchor Movement (SAM) and this relative SAM for soft soil (0.345 cm) is much more than for the hard rock site (0.038 cm). A structure on soft soil may experience a ground displacement of 20 cm and amplified displacement of 3.0 cm whereas same structure on hard rock may experience a ground displacement of 3.0 cm and an amplified displacement of less than 1.0 cm.

Comparison of actual recorded floor spectra with basement spectra for NPPs in Japan

In addition to the analytical study for hard rock and soft soil, comparisons are also available between the actual recorded floor response spectra with the basement spectra for two NPP sites in Japan. The Kashiwazaki-Kariwa (KK) NPPs in Japan which are on soil with an average shear wave velocity of 400 m/sec, witnessed a 6.8 M earthquake at 16 km epicenter distance with a depth of focus of 17 km on 16th July, 2007. Similarly, Shika NPPs in Japan which are on rock sitewith an average shear wave velocity of 1500 m/sec, witnessed a 6.9 M earthquake at 18 km epicenter distance with a depth of focus of 11km on 25th March 2007.

For hard rock site of Shika, the comparison of the floor response spectra of basement with 2nd, 4th,5th floor & roof of reactor building indicate that up 1.7 Hz frequency, there is no amplification of the ground motion irrespective of floor location [Ref-5]. The spectral peak for Shika NPP occurs at around 5 Hz. Similarly,

for soil site of Kashiwazaki-Kariwa, comparison of the floor response spectra of basement with 2nd & 3rd floor of different units of RB indicates that upto 0.7 Hz frequency, there is no amplification of the ground motion irrespective of floor location and even upto 1 Hz, the amplification is only 20% [Ref-6]. The spectral peak for KK NPPs occurs between 1.5 to 2.5 Hz.

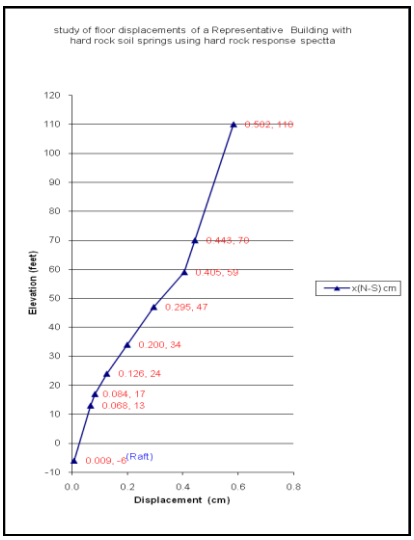

Fig.5: Relative displacement at different floor of building with hard rock spectra
Note: The maximum ground displacement is 3cm

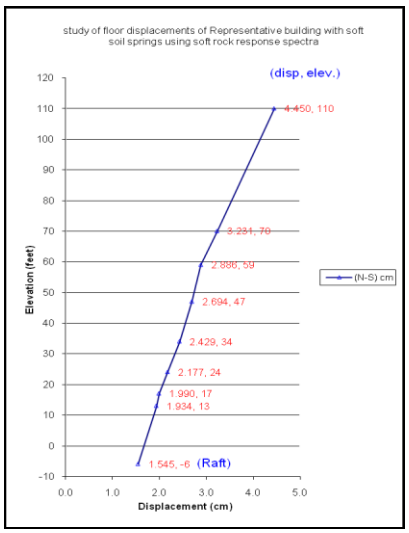

Fig.6: Relative displacement at different floor of building with soft soil spectra
Note: The maximum ground displacement is 20cm

REASONS FOR THE SUPPORTS BECAME RIGID IN CASE OF NUCLEAR POWER PLANTS

Most of the high temperature piping in general industries are supported by spring hangers & rod hangers. Similarly, the cold piping are supported by rod hangers or trapeze type supports which are of pendulum types. As the safety related piping for NPPs are required to be qualified by analysis using Finite Element Method (FEM) for earthquake loading, it requires calculation of fundamental frequencies. As the calculation of fundamental frequency of pendulum by FEM is not possible the upper end of the rod was required to be fixed for analysis as well as in reality. This led to the frequency of the piping going up from pendulum frequency of 0.5Hz to 2 Hz resulting in piping attracting an acceleration of 0.8g and 1.4g on medium rock & soft soil respectively instead of attracting an acceleration of 0.03g & 0.3g resp. As the 10mm dia. rod section was not able to meet the stress criteria for such high acceleration, it got changed to ISA50, ISMC100, ISMC 100 box support section, thereby increasing their stiffnesses and frequency. Being in the ascending part of the spectra, the piping & the supports attracted more acceleration, increasing the stresses in the pipe and support necessitating reduction in piping span between the seismic supports and increasing the support section size further more. This process of providing rigid supports and reducing the support span continued, till the piping frequency went in the descending part of the spectra. To achieve this high frequency for cold piping, the seismic supports were provided practically with U-bolt at every dead weight span and thus making the piping system rigid with these heavy supports. This is not the design by analysis but design to suit analysis.

For analysis of the piping floor response spectra are used. The opinion of the experts was that the supports with low stiffness and low frequency will amplify the floor motion to be experienced by the piping. This required modeling of the supports along with the piping to account for the supports amplifing the motion from the floor to the piping. Some 40 years before, with the type of computers available that time, the eigen value analysis of a simple piping system even with 20 nodes itself was not possible, then the analysis of the piping with support was just not possible. The other solution by the experts was to make the support rigid by increasing their frequency, to say 33 Hz, so the supports will not amplify the floor motion and same floor motion can be applied to the piping without the requirement of modelling of piping and supports together. For this, a simple method adopted was to have support stiffness 10 times that of the piping stiffness.

One more reason for supports getting rigid was the damping values used for piping in the analysis. The damping values used earlier were 1% for OBE & 2 % for SSE (for pipes <12" size) and 2% for OBE & 3% for

SSE (for pipes <12" size), resulting in higher response which have now been increased to 5% for OBE & SSE for all piping sizes

RESPONSE OF PIPING, DUCTING & CABLE TRAYS WITH ROD HANGER TYPE SUPPORTS AND RIGID SUPPORTS

The piping, ducting and cable trays provided with rigid supports will have fundamental frequency of 4–6 Hz. If it matches with the fundamental frequency of building structure, then it will attract accelerations varying from 2g to 3.5g on hard rock depending on their locations at different elevations of the building. Whereas a flexible piping, ducting or cable trays supported with hanger rods will have a frequency of 0.5 to 1 Hz and will attract an acceleration of only 0.03g to 0.1g on hard rock and upto 0.5g on soft soil (Figures-3&4).

Response of piping with rod hangers

A long unsupported length of piping without any lateral support or rigid support, similarly ducting & cable trays supported with rod hangers will have frequencies of 0.5 to 1 Hz and will attract lower accelerations and even with large mass of long length of piping will generate lower forces and moments

i) on the nozzles of the vessels/tanks
ii) on to the bellows of the ducting or the fan of the ducting or on the cable and cable trays going to the rigid supports on walls
iii) on to the cables and cable trays going to the panels.

Though the accelerations are low in this frequency region which is mostly governed by displacement, the displacements are higher. The piping, ducting & cable trays will experience the displacements of the order of 0.06 cm at 17 ft & 0.58 cm at 110 ft elevation for the building on hard rock and of the order of 1.5 cm at 17 ft & 4.45 cm at 110 ft elevation for the building on soft soil (Figures-5&6).

Response of piping, ducting & cable trays with rigid supports

Short distance piping running between vessel & equipment or between vessels or piping supported with rigid supports at shorter spans or ducting and cable trays with rigid supports, all will have higher frequency and will attract large accelerations for hard rock site. However, such rigid piping/ducting/cable trays, have low mass because of shorter length of the piping, ducting and cable trays between the short length rigid supports. As such, the product of increased acceleration and decreased mass is practically same. Furthermore, the rigid supports of heavy sections are capable of withstanding such large forces and moments. As such the piping, ducting & cable trays with rigid supports at short span length also get qualified for seismic loads even though they attract increased acceleration.

EXPERIENCE BASED DATA ON PIPING, CABLE TRAYS AND DUCTING

The earthquake experience based data on piping, piping, cable tray & ducting systems have been collected from the industries which have witnessed earthquakes of Koyna (1967, 6.5M), Bhuj (2001,7.6M) & Muzaffarabad (2005,7.6M). Out of hundreds of kilometers of piping, only three failues in piping have been observed

Earthquake experience based data suggests that distribution systems viz., piping, cable tray and ducting both with rod hangers and with rigid supports have survived large earthquakes and there are no failures of the piping systems because of inertial forces. Rather piping failures which were observed were because of seismic anchor movement to a rigid piping and due to movement of heavy equipment viz., economizer connected to small diameter rigid piping. The details of the experience based data are brought out below :

Failure Due to Seismic Anchor Movement and not due to inertial load

Vent line connected to an economizer line in KLTPH Panendhro (small rigid piping connected to bigger equipment:

A 1" vent line is provided on a 150 NB feed water line coming to the steam drum from the economizer. The vent line had a clamp at a distance of about 1.5m from the bend. Because of axial movement of the steam drum and also the economizer line to which the vent line is connected also moved along the axis of the vent line pipe during the earthquake motion. The clamp on the vent line was very firm, which did not allow the pipe to move axially. The inertia force induced from the steam drum to the economizer line is to be resisted by this small vent pipe resulted into the failure of the vent pipe near the bend (Fig. 6). Failure would not have occurred

if the clamp would not have become firm on the vent pipe. There was another vent line on the adjacent economizer line which had a small bend before the clamp support (which was not firm) and at a longer distance from the bend did not fail [Ref-7].

Fire water piping on a jetty of IFFCO

Three fire water pipe lines of 200 NB size go over the jetty approach to the jetty platform where the ships are anchored to download the Ammonia and $P_2 05$ acid. The length of the jetty approach up to the jetty platform is about 200m. Each segment of the jetty approach is about 6m in width and about 50-60 m in length. Such 4 segments make the total length of 200m of the jetty approach. The jetty platform, which is about 10m in width and about 100m in length, is normal to the jetty. The jetty platform is also made up of 2 segments of 50m length. The segments of the jetty approach & platform are made up of concrete with pile foundation, with piles going up to 30-40 m in the ground. At the junction between the segments, there is a gap and during seismic

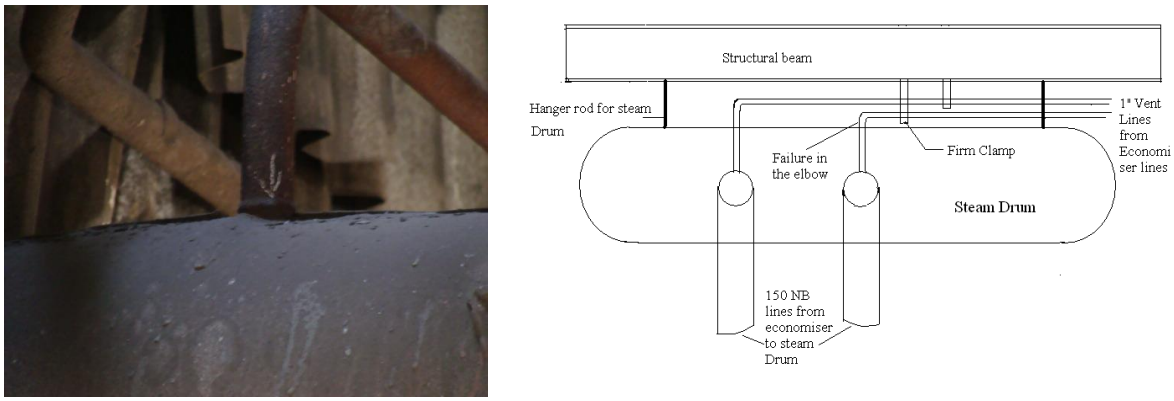

Fig 6 : Vent line connected to the Economiser line which saw failure at the elbow due to SAM

motion, two adjacent segments of the jetty have moved out of phase by about 7-8cm. Three fire water pipe lines go over the jetty approach and from jetty approach to the jetty platform as shown in Fig-7. Two lines go from the jetty approach on to the jetty platform with a bend having one support before the gap on the jetty approach and another after the gap on the jetty platform. The two pipelines have vertical branches before the elbow. The major direction of ground motion at Kandla was in North-South direction, which is normal to the length direction of the jetty approach. The jetty approach have seen a displacement of about 7-8 cm in North-South direction with respect to the jetty platform. The two pipes at the bend location have experienced such seismic anchor movement and failed at the bends. One of the vertical branch pipe of these piping also has experienced a failure. However, another 200 NB fire water pipeline which also goes from the jetty approach to the jetty platform, but having a vertical loop before going to the jetty platform making it flexible has not failed, even though it has also experienced the same seismic anchor movement[Ref-7].

Damage to the supports of the piping on Kandla Port Trust (KPT) jetty

Number of pipe lines go from Kandla Port Trust to IFFCO plant and are supported on a steel frame structure with two columns and a beam with the piping resting on the beam. Such column & beam supports spaced at a distance of about 7m are supported on the jetty. The piping runs over a length of about ½ km to 1 km. The jetty is made up of small sections of concrete slabs resting on pile foundation, about 6m in width and about 50m in length. During earthquake, at the gap between two adjacent slabs of the jetty, out of phase motion is generated. Two consecutive supports on the piping had bracings between the vertical columns of the support structure. In the case of IFFCO, there were no bracings between the columns on two sides of the segments of the jetty, whereas as in the case of Kandla Port Trust, there were bracings on the support columns on the two sides of the segments of the jetty. This resulted into the failure of the bracings, because of the seismic anchor movement and also led to the failure of the supports, resulting into the piping coming out of the supports & falling down by about 2m and resting on the jetty (Fig.8). Even though the supports have failed and the piping over a length of 200m have come down on the jetty by about 2m, there was no failure of the piping i.e no breach in the pressure boundary integrity of the piping [Ref-9].

No failures of piping due to inertial load

No failure in steam line, feed water line, BACW &TACW piping of the GEB jJamnagar & KLTPS, Panendro

There was no case of failure in the pipeline because of inertial loads. Steam lines coming down from 57m elevation from the boiler to the steam turbine located at 2m elevation have witnessed the earthquake without any failure. The boilers, boiler feeders, headers and the steam line, all are supported by rods and spring hangers have performed well during the 7.6 magnitude Bhuj earthquake in thermal power plants which are on hard rock (KLTPH, Panendro; GEB Thermal Power station, Sikka Jamnagar). Similarly, the feed water piping, Boiler Auxiliary Cooling Water (BACW) and Turbine Auxiliary Cooling Water (TACW) piping have also survived without any damage [Ref-7].

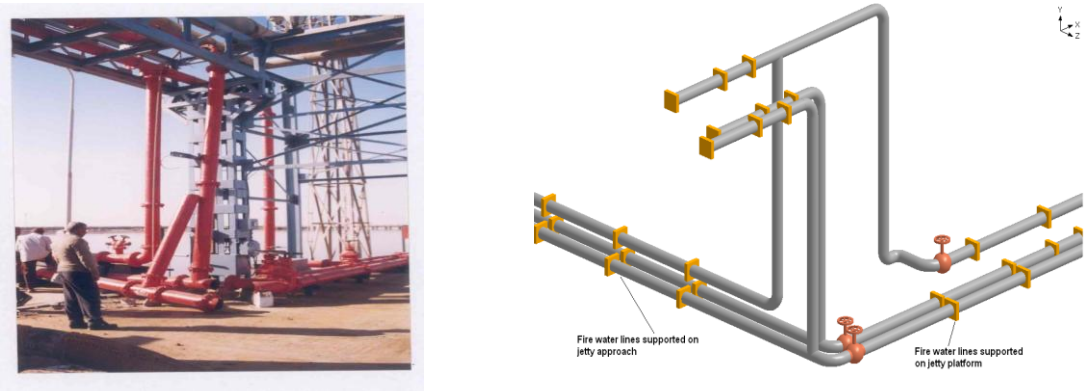

Fig. 7 : Failure of fire water lines on the IFFCO jetty

Fig. 8: Failure of Piping supports running between IFFCO and Kandla Port Trust Jetties

Fig. 9 : Piping supported for only dead weight at KLTPS, Panendro

No Piping Failure in GSFC fertilizer plant in Jamnagar

Large length of Ammonia and Phosphoric acid pipe lines coming from the shore terminal the plant having length of 12 kilometers have withstood the earthquake without any failure. Theses piping are supported on concrete racks having height of 8 meters. The piping have mostly dead weight supported with guided supports for Ammonia piping and U-bolt supported at every 5 dead weight support interval for majority length and at every 3 dead weight support interval near plant site (one interval of 4 meters) for Phosphoric acid pipe line. The guide supports were provided to give direction to the piping expansion for thermal expansion and not for seismic resistance. For ammonia piping, U-clamps were observed with a gap of 10-20 cm which are meant for wind load, so that they should not come out of the piping racks during cyclone [Ref-7].

No failure in general piping from the Industries

In the experience based data for piping which witnessed Bhuj 7.6 earthquake, , there were fire water piping on KPT jetties 1 to 4, some of which were just resting on floor for Dead Weight (DW) without pedestal & without Lateral Supports (LS), some are resting on pedestal for DW without LS. In few of the industries, the piping were having lateral supports at 5 to 6 DW spans, at 3 to 4 DW spans, at two DW spans, at every DW span or simply resting for dead weight (Fig-9). All these piping which experienced PGA ranging from 0.24g to 0.6g, have withstood the earthquake inertial load without failure [Ref-7&8].

PHILOSOPHY OF SUPPORTING THE PIPING FOR HARD ROCK SITE AND SOFT SOIL SITE AND WAYS TO ACCOMMODATE SAM

As evident from the spectral shape for hard rock and soft soil site, the support span need to be different depending on the type of soil. For hard rock site, with flexible piping having lateral supports at every three dead weight span, the piping frequency will be around 1 Hz and will be away from the spectral peak of 10-20 Hz. A rigid piping with 4.0 to 5.0 Hz frequency will attract accelerations varying from 2g to 3.5g on hard rock depending on their locations at different elevations of the structure. Whereas a flexible piping, ducting or cable trays supported with hanger rods will have a frequency of 0.5 to 1 Hz and will attract an acceleration of 0.05 to 0.1g on hard rock. So, provide lateral supports at every three or more DW span for hard rock site.

However, it may be remembered that majority of the piping failures are due to seismic anchor movement given to rigid piping. As such, in case of rigid piping, it should be designed for seismic anchor moment at the design stage.

The experience based data showed that piping never failed due to inertial load, but failed due to SAM. Provisions must be made during the design stage itself to accommodate the relative SAM. The movement of main run piping to which the branch piping is connected causes the branch pipe to witness SAM. It is usually more practical to design the branch piping and connection with sufficient flexibility to accommodate the anticipated motion of the main run piping. When the piping systems runs between two different building structures or pass through construction joint, they may get subjected to out of phase motion of the two separate structures resulting in the piping getting subjected to large resultant relative motion. Depending on type of soil, the piping may experience relative differential building motion of 3 to 20 cm or more. For flexible pendulum type of supports, at the end of simple harmonic motion, the velocity is very low or zero resulting in very low or zero impact energy, if there is any interaction between the systems. Morever, No failure of piping or piping components viz., valves, flanges have been observed in the experienced based data on piping which have seen 0.6g peak ground acceleration (pga) on soft soil and 0.24g pga on hard rock.

VENTILATION DUCT

Ventilation ducts which supply ventilation air to control room, or to the transformer rooms have survived the earthquake without damage at Koyna, as well as in the industries which experienced Bhuj earthquake.

The ducts were of sizes varying from 2m x 1m to 0.5m x 0.2m in size. The supports were rod type supports with hooks from the ceiling level and ISA 40 angle connected to the rods by bolts on which the ducts rest (Fig-10). The support height varies from 1 to 2 m. Since ducts are light mass system, the supports should be flexible with rod hangers which is also the case in the experienced based data which survived the Koyna and Bhuj earthquake [Ref-7&8]. Since the supports are flexible, while laying the duct, care should be taken for seismic interaction so that they should not interact with adjacent structure/equipment by keeping sufficient gap between them. Morever, no failure of ducting system or its components have been observed in the experienced based data on ducting which have seen 0.6g peak ground acceleration (pga) on soft soil and 0.24g pga on hard rock.

Fig. 10 : Ducting supported with rod hangers from the industries which witnessed Bhuj 7.6 M Earthquake

CABLE TRAYS & THEIR SUPPORTS

The Cable tray supports in KLTPS, KDPH, Koyn, Stage I to IV Plants, IFFCO, GSFC, KPT and Digvijay cement are generally made up of ISA 50x50x6, ISMC 125 or ISA 100 either supported from wall or supported from ceiling have survived during Koyna and Bhuj earthquakes (Fig-11) [Ref-7&8].

Because of the rigid support concept, for a multi-tier cable tray system, heavy supports made up of heavy ISMC 250/350 box sections were being used in NPPs. Experience based data shows that even rod hangers supported cable tray system have survived. The supports can be made be made flexible by using rod hangers/threaded rods (with spherical washer at top, so it does not attract any moment) as it acts like a pendulum (low frequency < 1 Hz), will not attract high acceleration (Fig-12). In this case also, as the supports are flexible, care should be taken for seismic interaction so that the trays and their supports do not interact with the adjacent structure/equipment. This can be achieved by keeping sufficient gap between them and also the cables before getting connected to the panels or equipment should be provided with additional length to account for the differential seismic motion between the cables and the equipment. Morever, no failure of cable tray system or its components have been observed in the experienced based data on cable tray sytem which have seen 0.6g peak ground acceleration (pga) on soft soil and 0.24g pga on hard rock.

Fig 11 : Cable tray in General Industries

Fig 12 : Flexible Cable Trays support

CONCLUSION

Based on the performance of piping in the field from the industries which have witnessed earthquakes of Koyna (1967, 6.5M), Bhuj (2001,7.6M) & Muzaffarabad (2005,7.6M), it is seen that irrespective of the piping systems and its supports being flexible or rigid, there were no failures in the piping due to inertial load. Only failure observed were in the rigid piping subjected to SAM and movement of a large diameter piping or heavy equipment connected to a small diameter rigid piping. To avoid this type of failure, the solution is to have a flexible piping which can resist SAM.

It is also seen that the ground motion for the Stable Continental Region and the Active Tectonic Region have different spectral frequency content. For this varying spectral shape, depending on the site type, the accelerations to which the distribution system will be subjected will be different and this will lead to different supporting spans for these systems based on the soil type and the plant being in ATR or in SCR.

From the analytical studies as well as from the recorded floor spectra which witnessed earthquakes, it is seen that upto 1 Hz frequency, there is practically no amplification of the ground motion, irrespective of the floor elevation for hard rock and soft soil site. Thus, if we have a piping with lateral supports at with every three dead weight spans, it will have a frequency of about 1 Hz or below & will be away from the spectral peak frequency for the hard rock and will attract low acceleration. The ground displacement and relative floor displacement i.e. SAM are lower for hard rock site compared to soft soil site. To accommodate the SAM, which is the main cause of failure of the piping, the piping need to be made flexible. However, if we make the piping flexible, the concern of impact with adjacent structure/equipment should be properly addressed by keeping sufficient gap between them. However, no failure of piping system and its components have been observed in the experienced based data on piping which have seen 0.6g pga on soft soil and 0.24g pga on hard rock.

Similar to the piping, the cable tray system as well as ducting system should be made flexible using rod hanger type of supports which will attract lower acceleration. However, in this case also, the concern of impact

with adjacent structure/equipment should be properly addressed by keeping sufficient gap between them. Morever, no failure of cable tray system and ducting system have been observed in the experienced based data on these sytems which have seen 0.6g pga on soft soil and 0.24g pga on hard rock.

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REFERENCES

[1] Gail M. Atkinson and David M. Boore (2006) "Earthquake Ground Motion Prediction Equations for Eastern North America" by *Bulletin of the Seismological Socity of America, Vol 90, No.6, pp.2181-2205*

[2] David Boore & Gail M.Atkinson (2008), "Ground-Motion prediction equation for the average horizontal component of PGA, PGV and 5% damped SA at spectral periods between 0.01s and 10.0s", *Earthquake Spectra, Volume 24, No. 1,pp. 99-138*

[3] Internal report (2010) on "Seismic studies carried out for NPP buildings for ground motion on Stable continental Region and Active Tectonic Region"

[4] ASCE-4, (1998), "Seismic Analysis of Safety-Related Nuclear Structures and Commentary", American Society of Civil Engineers

[5] Presentation on "Seismic Safety Evaluation of Shika Nuclear Power Plant after the Noto Hantou Earthquake" by Hokuriku Electric Power Co. in International Workshop on Lessons Learned from Strong Earthquakes, Organized by the *International Atomic Energy Agency, 19–21 June 2008, Kashiwazaki, Japan*

[6] IAEA Mission Report, Volume II (2007), "Preliminary findings and lessons learned from the 16 July 2007 earthquake at Kashiwazaki-Kariwa NPP", 6 – 10 August 2007, Kashiwazaki-Kariwa NPP and Tokyo, Japan

[7] Report on BRNS Project No 2005/36/16 on "Earthquake experience data from industries that witnessed Bhuj earthquake 2001", ERDA Baroda

[8] Report on BRNS Project No 2005/36/46 on "Earthquake experience data from industries that witnessed Koyna earthquakes", Govt. Engg. College, Karad

[9] Earthquake Spectra (2002), supplement A to volume 18 on "In 2001 Bhuj, India Earthquake Reconnaissance Report", Earthquake Engineering Research Institute