SPECIAL CHARACTERISTICS OF SEISMIC DAMAGES TO UNDERGROUND PIPES

by K. KUBO

1. Piping System and Ground Movement

Except the specific cases, the failure of buildings and bridges are mainly caused by the inertia force due to an earthquake. If the yield strength of structure is less than the inertia force, the structure will suffer seismic damage. In case of underground pipes, however, the inertia force of pipe and the inner liquid during an earthquake is resisted by the soil which supports the pipe and in general the force of the latter is far larger than that of the former. On the other hand, if the soil supporting the pipe is displaced by the liquefaction of sandy soil or by the fault, the pipe is forced to move with the sandy soil. This movement of the ground surface is the main cause for seismic damage to underground pipe and the inertia force acting on the pipe is not the cause for its damage. The past examples of damage to the piping resulting from earthquakes have justified the above fact. Moreover, there was no instance of seismic damage that contradicts the above fact in the San Fernando Earthquake.

Description will be given of some examples how the movement of the ground surface during an earthquake has detrimental effect upon the piping and breaks it down. The first instance, of which Prof. Okamoto has already pointed out, is that there was fairly remarkable difference between the seismic damage ratio of water pipes and that of wooden houses in the Kanto Earthquake. That is, the seismic damage ratio of wooden houses was higher in alluvial district and lower in diluvial land; on the other hand, the seismic damage ratio of water pipes showed a high value on the border of alluvial and diluvial districts and showed an intermediate value in alluvial district. It can be considered that this fact indicates the pipe in the ground uniformly moving suffers less damage, even if the vibrational amplitude and acceleration are large (the seismic damage ratio of wooden houses comes to be high), but on the contrary the pipe connecting two points which have different vibrational movements is subjected to large tension or compression, which finally brings it to yeilding. The second instance is the field experiment on the underground pipe. The group mainly organized by the members of Central Research Institute of Electric Power Industry has made the experiment by taking advantage of the Matsushiro Earthquake. Judging from the report presented from this group, strain caused in the pipe is more distinguished in axial strain than in bending. That is, because the wave-length of seismic wave is long, the radius of curvature of bending deformation of pipe is large, thus resulting in small bending stress of pipe. However, the phase difference of surface wave deforms the pipe very much in the axial direction.

The third instance is the seismic damage to water pipes in the Niigata Earthquake. In case of the Niigata Earthquake, subsiding (caused by dragging of the subsided buildings) and upheaving of pipings were observed due to the liquefaction of sand in addition to the phenomena described for the above two instances. According to the results of author's investigations in which attention was paved to the relation between the movement of ground and the seismic damage ratio of water pipes, the following matter was confirmed: when we examined the seismic damage ratio of the pipes, for both axial and lateral directions, the former showed much higher value than the latter. This means that the seismic damage to underground pipes is mainly caused by axial deformation rather than bending.

Three examples of seismic damage to underground pipings mentioned above indicate in common that the weak point of piping from the view-point of earthquake engineering is concerned with forced deformation and yield strength of the piping in the axial direction and also that influence due to bending deformation to seismic damage is small. Moreover, it may be understood from those examples that the underground pipe which connects two points vibrating in different amplitudes due to the differences of soil structure and depth of soil layer, or the pipe crossing surface crack is easy to suffer seismic damage during earthquakes.

2. Seismic Damage to Gas Pipes

Gas pipes have been installed by two companies in the district suffering seismic damage. The one was the Southern California Gas Co. and the other Pacific Lightening Service Co. The pipe of the former was 400 millimeters in diameter, layed in Glenoaks Blvd, and was running through the City of San Fernando. The pipe of the latter was 650 millimeters in diameter and was running south along the San Fernando Road. Though we could not have any explanation by an engineer of the latter company directly, an engineer of Southern California Gas Co. said that the pipe of 650 millimeters diameter was arc-welded ones and suffered only slight seismic damage. It is unaccountable that this pipe suffered only minor seismic damage because it crossed two faults at the neighborhood of the Juvenile Hall and at the northwestern district of San Fernando City. The Survey Mission of Tokyo-To reported that, judging from aerial photogrammetry and the like, the pipe suffered similar damage as that of the pipe of 400 millimeters diameter, but that the details have not been given yet. Thus, it still remains unexplained what part of the pipe suffered what kind of seismic damage. The above is the only information we have obtained about the 650 millimeters diameter pipe.

Then, we will explain here the damage to 400 millimeters diameter pipe of Southern California Co. Failure due to buckling was caused at two places where the pipe was crossing the faults. The other failures were all tensile fractures of the pipe, the number of which came up to fifty-eight. Tensile fractures of the pipe occurred at about six-meter intervals and the maximum width of opening was 6.5 millimeters. The width was large near the crushed part, gradually smaller with being off the crushed part, and was finally reduced to hair crack. The pipe was constructed in about 1920 using gas-welding; therefore, the strength of the welded joint was smaller in comparison with the base-metal. It is considered that this is the reason why the pipe suffered tensile fractures at about six-meter intervals, namely, at each welded joint.

The gas pipe layed in Hubbard St. and crossed at right angles with 400 millimeters diameter pipe in Glenoaks Blvd suffered no damage. An engineer explained that the pipe might not be damaged because it was an arc-welded pipe. In reality, however, it is presumed that no damage of the pipe is due to not crossing any fault. The seismic damage ratio of distributing pipe of water service was also low in Hubbard St.

3. Suggestions for Aseismic Design of Piping System

Consideration on acceleration is not necessary for aseismic design of piping system, but one on relative displacement is essential. The engineers of the oil companies in U.S.A. insist on this opinion in designing the oil pipes, and this may be right. Therefore, tension and compression of piping due to axial relative displacement are the most noticeable forces, but bending deformation of piping is not so important for its aseismic design. The past earthquake damages have justified this fact. Moreover, we understand theoretically that axial deformation is more important than bending.

Then, some items to be noticed and investigated for aseismic design of piping system will be mentioned about hard and soft soils respectively.

In hard soil, it is clear that vibrational amplitude of seismic ground movement is small. Therefore, the piping system in uniform hard soil may be earthquake-proof so far as no surface crack and fault occur.

Measures to counter the fault are as follows:

1) Selecting the piping route avoiding the fault which may come out.

2) Using a ductile pipe. Steel pipe is superior to cast-iron one, and welding at the joint must not weaken the strength of the piping. Steel pipe is resistible enough for the fault if it is not so large.

3) Providing the loops to a piping system to accommodate its axial deformation.

4) Preparing a mat filled with loose sand around a piping in order to loosen the restriction to it and to displace it more easily.

5) Using flexible joints or expansion joints in order that unusual axial tension or compression might not be caused in the piping.

6) Arranging the valves adequately and making the system which has no dead end in order that seismic damage due to the failure of piping might be the most slight.

In soft soil, first, we should pay attention to liquefaction of sand during an earthquake. Particularly, in case of a pipe with large diameter, it is important whether liquefaction of sand is caused or not. Next, relative displacement between two points on the axis of piping system, especially the displacement along its axis is important for aseismic design. In the past, the relation of the depth of soil layer or geological features to the acceleration of an earthquake was thoroughly investigated, but entirely not to the vibrational amplitude of the ground because of the difficulties in measuring their values. Hereafter, the investigations in this field have to be done in discussing resistance against earthquake of piping system. In case that relative displacement between two points on the axis of a piping system is forcast, the guide for its aseismic design will be as follows:

1) Reducing the stress of pipe by using expansion joints.

2) Decreasing Coulomb's friction of the pipe to the soil around it.

3) Strengthening the pipe in axial tension and compression by increasing plate thickness and amount of steel and employing the best welding method.