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ASEISMIC TECHNOLOGY AND SAFETY EVALUATION OF GAS DISTRIBUTION SYSTEMS

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SUMMARY

We report here on the aseismic technology and safety evaluation method for gas pipelines employed by Osaka Gas. Antidisaster measures against earthquakes for gas pipeline networks consist of: (1) preventive measures, (2) emergency measures and (3) restoration measures. Preventive measures include aseismic techniques such as the use of polyethylene and steel pipes and the development and application of mechanical joints with high earthquake resistance. As emergency and restoration measures, an antidisaster system using the regional block supply method, etc. has been established. In this system, the gas service area is divided into wide-area blocks connected via high- and medium-pressure transmission pipelines, then into small blocks serviced via medium- and low-pressure distribution pipelines. The safety of high- and medium-pressure transmission pipelines laid across wide-area blocks has been confirmed through the evaluation of their resistance against seismic waves and ground deformation, in which respective installation conditions, ground characteristics, etc. are taken into consideration. Through this system, gas service in wide-area blocks which may cause secondary calamities can be suspended in the event of an earthquake as emergency measures, while service can be continued without interruption in other blocks. Wide-area blocks are divided into small blocks based on the prediction of damage, in which the strength of pipes and joints of distribution pipelines and ground conditions are taken into consideration. This system allows prompt and safe restoration of gas service after suspension.

INTRODUCTION

As gas pipelines are installed over a wide service area, conditions related to pipes such as the quality of surrounding ground differ widely. Furthermore, gas pipelines use various pipeline materials and jointing methods. In particular, existing gas pipelines have been constructed over a long period, and enormous expenses are required to reconstruct or repair all of these pipelines to make them earthquake-resistant. From the viewpoint of gas supply, gas pipelines comprise two types: (1) transmission pipelines, which convey a large volume of gas and extend fairly widely but occupy a limited area, and (2) distribution pipelines, which supply gas directly to customers and are installed over a wide area. A large number of distribution pipelines branch off from a relatively small number of transmission pipelines called trunklines. Pressure is also classified into high, medium and low pressure. The service area is so extensive that earthquake damage is expected to vary from place to place with the epicentral location, earthquake magnitude, ground characteristics, pipeline conditions, and other factors. Comprehensive antidisaster measures against earthquakes are, therefore, essential to gas pipeline networks.

BASIC POLICY FOR ANTIDISASTER MEASURES AGAINST EARTHQUAKES FOR GAS PIPELINE NETWORKS

Antidisaster measures against earthquakes for gas pipeline networks are basically composed of the following three categories (Ref. 1):
(1) Preventive measures: To prevent and minimize gas pipeline damage.
(2) Emergency measures: To prevent secondary disasters due to gas leakage and secure gas supply where possible.
(3) Restoration measures: To promptly and safely resume suspended gas supply.

In elaborating antidisaster measures against earthquakes, newly constructed and existing gas pipelines should be dealt with separately.

As for newly constructed pipelines, high-pressure pipelines are designed so as to be earthquake-proof under all conceivable conditions based on ground conditions, while earthquake-resistant materials for pipes and joints as well as flexible piping are used for medium- and low-pressure pipelines: i.e., preventive measures, by means of aseismic design and technology, are utilized for these pipelines. For existing pipelines, which cannot be replaced or repaired with earthquake-resistant pipes within a short period, an antidisaster system incorporating an emergency gas shutoff method, regional block supply method, information collection network, and restoration plans should be established, while repeating education and training of related personnel to ensure smooth and complete implementation of emergency and restoration measures in the event of an earthquake.

ASEISMIC TECHNOLOGY FOR GAS PIPELINES

The required level of earthquake resistance for gas pipelines has been determined based on the analysis of damage caused by previous earthquakes. This requirement has been met satisfactorily through techniques developed and utilized by Osaka Gas, which include:

(1) Use of highly ductile pipe materials such as polyethylene, steel, and ductile cast iron.
(2) Use of mechanical or flexible joints with high earthquake resistance for connecting pipes. (See Fig. 1.)
(3) Use of direct-burying valves for gas shutoff to ensure the uniformity of pipeline materials and continuity of pipeline behavior. (Conventional valves are encased in concrete boxes.)
(4) Three-dimensional piping using bent pipes (for portions passing through buildings, etc.).

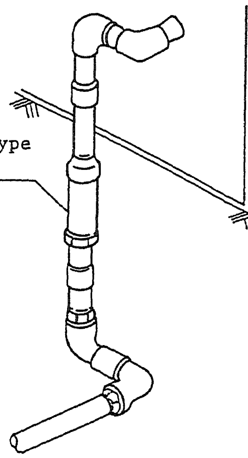

Fig. 1 Piping Using an Extension Joint

EARTHQUAKE-RESISTANCE EVALUATION OF EXISTING GAS PIPELINE NETWORKS

To ensure emergency measures for smooth and effective prevention of secondary disasters, due to gas leakage as well as restoration measures for prompt and safe resumption of gas supply, it is necessary to establish in advance an antidisaster system using the regional block supply method, etc. for the existing gas pipeline network. Since the gas service area is extensive, pipeline damage is expected to vary from place to place with the epicentral location, earthquake magnitude, ground characteristics, pipeline conditions, etc.

The gas service area has been divided into wide-area blocks (called "super blocks"), so as to suspend gas supply where a secondary disaster due to gas leakage is foreseeable but to continue service in other places, in response to damage distribution and local information. Gas is transported between wide-area blocks via high-pressure (10 kg/cm^2 or more) and medium-pressure transmission pipelines (5 to 7 kg/cm^2) only. Between such blocks, facilities are installed which can shut off gas by radio remote control. Medium-pressure distribution pipelines (1.5 kg/cm^2) are always kept shut by means of valves, and low-pressure pipelines are kept disconnected.

To establish the wide-area block system, it is essential that transmission pipelines are safe and can function sufficiently well in the event of an earthquake. Evaluation through earthquake response analysis has confirmed that transmission pipelines have sufficient earthquake resistance. For earthquake-resistance evaluation of transmission pipelines, the behavior of each route is analyzed, taking the ground characteristics and burying conditions along the route into account, in response to seismic waves and ground deformation simulated on the basis of past earthquake records, etc. Response analysis is conducted for seismic waves over the entire pipeline length and for ground deformation at specific points such as where liquefaction, fault displacement, landslide at steep slopes, and cutting-filling borders have occurred or exist.

Figure 2 shows transmission pipeline routes in a wide-area block. As an example, the earthquake response analysis of medium-pressure transmission pipelines for seismic waves and the evaluation of the results are shown in the following.

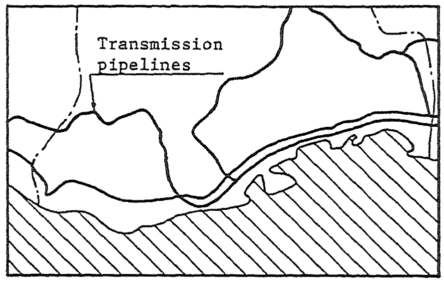

Fig. 2 Transmission Pipeline Network

Seismic Wave Input Seismic waves are of the Rayleigh wave type whose direction of propagation is the same as that of motion, and motion in the longitudinal direction relative to the pipeline, i.e. along the pipeline, is analyzed by inputting sinusoidal seismic waves.

Method of Analysis Earthquake response was calculated using ERAUL (Ref. 2), a program for nonlinear analysis of pipe earthquake response, to find the pipe strain in the pipeline subjected to seismic waves.

Safety Evaluation For allowable pipe strain, values given in the Recommended Standards for Earthquake-resistant Design of High-pressure Gas Pipelines (Ref. 3) published in 1982 were used.

Figure 3 shows the ratio of pipe strain to allowable strain (to be called the allowable strain ratio) plotted for each location along a medium-pressure transmission pipeline. At each location, the maximum allowable strain ratio is approx. 0.2, indicating that the medium-pressure transmission pipeline is sufficiently resistant to seismic waves. For ground deformation such as liquefaction, fault displacement, and landslide and ground discontinuity such as cutting-filling borders, the maximum allowable strain ratio is approx. 0.6, indicating that the pipeline is earthquake-resistant also under ground deformation and discontinuity, although these factors have a greater degree of influence than seismic waves. Additional consideration is necessary when a sliding collapse occurs over the entire slope.

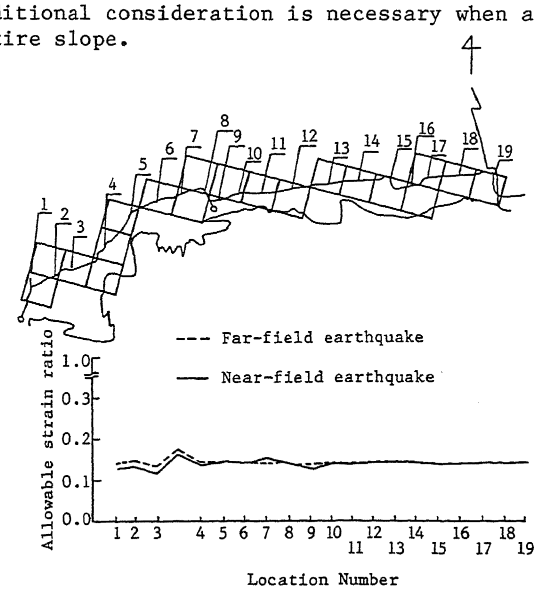

Fig. 3 Evaluation of Earthquake Resistance of a Transmission Pipeline

Distribution pipelines spread over a wide-area block, and pipes and joints are of various types. Ground conditions also vary widely from place to place. With regard to the earthquake resistance of distribution pipelines, earthquake response was analyzed in a similar manner, with the strength of joints taken into consideration (Ref. 4). Based on such analysis, pipeline damage was forecast by zone in each wide-area block. Figure 4 shows an example of such forecast.

Transmission pipelines are sufficiently safe and reliable to establish a wide-area block system. Distribution pipelines in a wide-area block are divided into "middle blocks" on the basis of terrain and pipeline conditions. This middle-block system facilitates local emergency measures and prompt restoration. A middle block is subdivided into "little blocks", so as to ensure prompt and safe resumption of gas supply. Figure 5 outlines these block systems.

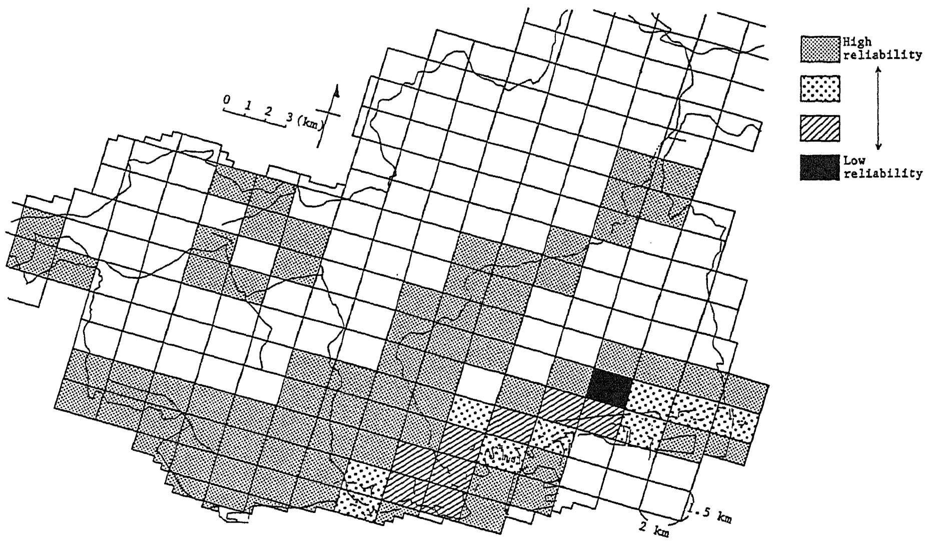

Fig. 4 Cases of Distribution Pipeline Joint Damage

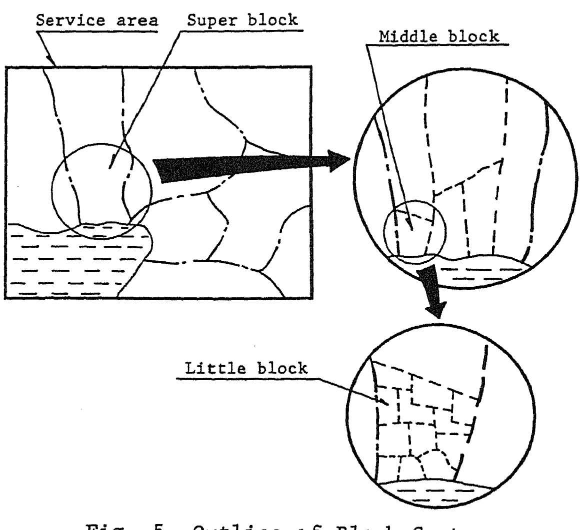

Fig. 5 Outline of Block System

CONCLUSION

As for newly constructed gas pipelines, reliability in the event of an earthquake has been greatly improved through aseismic design, the use of newly developed, highly earthquake-resistant joints, etc. As regards existing pipelines, transmission pipelines have been confirmed, through earthquake-resistance evaluation, to be reliable against earthquakes, leading to the establishment of an antidisaster system based on the block supply method. For distribution pipelines, damage has been forecast through earthquake-resistance evaluation. These provisions, in addition to the information collection network, repeated education and training of related personnel, and prepared materials and equipment, permit implementation of emergency and restoration measures designed to prevent secondary disasters due to gas leakage and to promptly and safely resume suspended gas supply.

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