FOREWORD

The word "tunnel" has conventionally meant a bore in rock in mountaines, but recently, tunnels has also come to be constructed in soft ground, and are being used for transportation facilities such as subway, for underground shopping centers,,etc., in seismic active areas. Consequently, the behaviors of tunnels during earthquakes have become diverse, and it is assumed that earthquake damage will take on various forms.

In contrast to forcible deformation occurring or self-vibration being induced in a surface structure during earthquake, it has been shown that a tunnel behaves in accordance with the displacement and deformation of the ground surrounding it. Therefore, when evaluating the earthquake resistance of a tunnel, the behavior of the ground during earthquake which is generally considered to be very complex must be known. It is not an easy matter to determine this behavior analytically from the dynamic properties of rock or ground. However, even if there were to be a large difference in the acceleration of earthquake motions in the comparatively high-frequency domain, it is not readily conceivable that very prominent relative displacements will occur at two neighboring points in the ground except in special cases. It is felt a limitation exists in this respect.

There have been two important earthquakes in this connection recently.

The behaviors of subway, sewerage tunnel in soft ground in the Mexico Earthquake of 1985 have been reported and are well known. On the other hand, the damage at the Kailuan Coal Mines in the Tangshan Earthquake of 1976 was compiled and published in 1986. According to the latter, two of the eight mines were in zones of seismic intensities 10 and 11 (Chinese Scale, around M M Intensity Scale), and were directly hit by the earthquake. There was severe damage with 56% of surface structures collapsing, while structures suffering heavy damage and medium damage amounted to 13% and 5%, respectively. When underground structures are considered divided into those shallower and those deeper than 10 m, the former were underground passages, drainage culverts, and pipelines, with damage considerable at points of poor ground conditions such as where liquefaction occurred or where seams had been mined out, and the damage to the passages and to the culverts occured mainly at the joint portions and the damage to the pipelines did mainly at the rigid joint. The damage at places of good ground conditions said to have been light for all structures. Regarding vertical shafts and adits of coal mines deeper than 10 m and reaching 1.000 m, damage to vertical shafts occurred to a given depth from the ground surface, and occurred often where the ground had liquefied, where the shaft walls were weak, or where the quality of work executed was not good. Damage in adits was mainly at the faults and in the vicinities, at portions of poor rock conditions,

where adits intersected each other, and where treatment of construction joints had been improper, and although slight, spalling of arch portions, cracking, and heaving of inverts had occured.

It should be noted that such damage, along with damage to tunnels at the time of the Mexico Earthquake of 1985, did not exceed the pattern of damage estimated from earthquake observations, vibration tests on models, and earthquake response analyses made up to that time.

It is true that behaviors of ground and rock ground are complex during earthquakes, but the earthquake resistances of tunnels may be evaluated from macroscopic judgments based on damage, and it is thought possible for countermeasures to be provided as a result.

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