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25. *Damage Probability of Line Structures due to an Earthquake.*

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1. Introduction

In this paper line structures are defined as the structures which constitute networks of utility, transportation and communication systems; railways, roads, water supply lines, electricity lines, and gas and oil lines. River-embankments may be also included in such structures in a wider sense. In a modern society, line structures are a vital component. The continuous functioning of a city's line structures is an accepted fact of life for the residents and the inconvenience of even a temporary obstruction in the services is not easy to tolerate. A failure of a line structure could be disastrous to the functioning of a city, particularly during and after an earthquake. Therefore, it is important that adequate precautions should be taken to avert, or at least minimize the effects of such a failure. However, the technology of earthquake engineering has not been itensively directed to the aseismicity of line structures. Only recently have engineers and engineering societies realized the consequences to the general public after failures of line structures due to earthquakes.

This paper presents a consideration of damage probability of line structures due to an earthquake from the viewpoint of system reliability.

2. Failures of Line Structures due to an Earthquake

A failure of a component of a line structure generally leads to stopping the function of the associated system, and particularly the failure due to an earthquake results in considerable losses and inconveniences in various forms:

i) Breakage of water supply piping system:
Inability, or at least difficulty in extinguishing fires and lack of drinking water for survivors after the earthquake.

ii) Stoppage of the electric power supply system:
Stoppage of disaster prevention instruments, and of elevators in buildings, disorder in traffic flow due to inoperative electric traffic

signals and drinking water supply.

iii) Damage of railways and roads:
Obstructions to the escape from fires which would most probably occur after an earthquake and obstacles to post-earthquake rehabilitation activities.

iv) Failure of river-embankment:
Possible cause of a flood and consequent destruction of human life and property in the adjacent area.

Studies of the past damage due to earthquakes indicate that these line structures are more easily damaged than ordinary building structures. A typical example can be found in the North Italy Earthquake of 1976. In Udine which is outside the intensively earthquake-damaged area, damage to houses was negligible, confined to the slips of roof tiles, while stoppages of the electric power system for several days, and moreover of the railway service for one month were reported. Although, from the reasons remarked earlier, line structures should be designed with higher reliability than ordinary structures, the past evidence shows nearly the opposite. To improve the aseismicity of line structures, first of all, it is important to consider the reasons why such structures are apt to suffer damage in earthquakes.

3. Damage Probability of a Line Structure

A characteristic feature of a line structure lies in its length and narrowness. Then, the basic assumption is herein made that a line structure can be represented by a series of unit structures as shown in Fig. 1 where a river-embankment is taken as an example. Although in this form the line structure may lose some of its characteristics as a continuous system, the proper choice of length topology and spatial distribution of unit structures can provide a good approximation to the true answer.

Damage probability p_T of a line structure can be defined as the probability that its function fails and, under the basic assumption made, is obtained in terms of the number n of the unit structures constituting the line structre and of the damage probability of each unit structure. Assume that all the unit structures are statistically independent and that their damage probabilities are equal to p. Accepting a series model for the line structure (Fig. 2), the theory of system reliability shows the total damage probability as p_T:

$$p_T = 1 - (1-p)^n \tag{1}$$

It should be noted that the definition of failure and the associated proba-

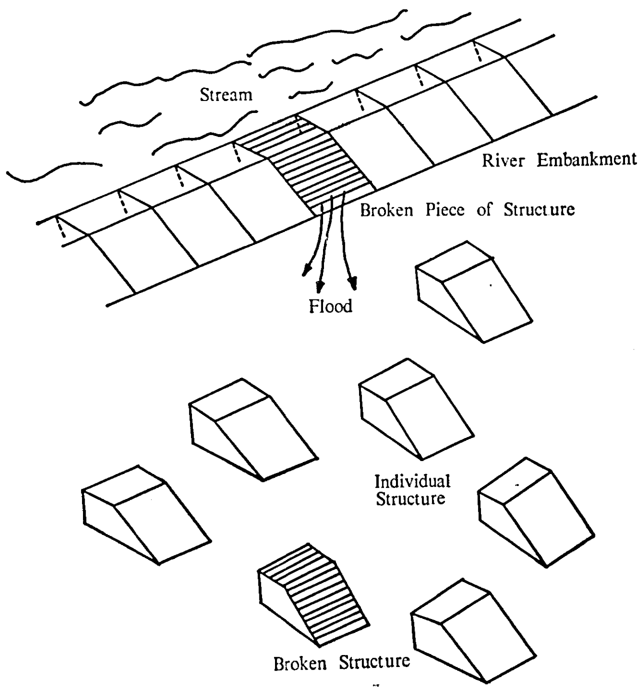
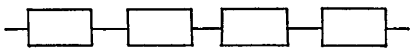
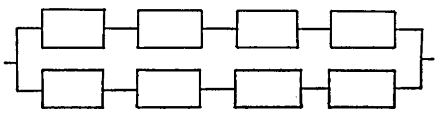


Fig. 1. A failure model of river-embankment.



Series System
(River Embankment, Railroad, Water Distribution System, etc.)



Mixed System
(Road, Electricity Distribution System, Telephone Network, etc.)

Fig. 2. Reliability model of line structures.

bility p of unit structures vary according to the types of line structures as well as the choice of the length of the unit structures. A mere crack in water or gas supply piping causing leakage may be regarded as a failure of the associated system. Similarly, a small crack in a river-embankment having a potential of partial breaking can be considered a failure. A 10 cm local foundation settlement paralyzes the function of a railway. In contrast, such a foundation settlement in a road brings practically no inconvenience to its function. Generally, in most line structures as remarked, however, one should take the probability of a relatively slight failure as the value of p. Then the value of p would be considerably larger than the probability corresponding to a complete failure of a unit structure. In addition, according to Eq. 1, the damage probability p_T becomes much larger than p as the number n increases. In conclusion, the author would like to point out that this explains why line structures appear to be easier to disrupt than ordinary buildings in which a wall crack is not considered serious damage.

4. Case Study

Water supply piping

KUBO, et al.[1] have reported that the damage rate per 1 km in the Kanto Earthquake (1923) averaged 0.22. The propability p_T that a failure occurred along 10 km water supply piping, leading to interruption of the water supply, is estimated as follows. First, assume that at most only one break point per 100 m water supply piping occurs and that 100 m is the unit length. Accordingly, the probability of failure in the minimum unit is $p=0.022$. The probability of failure p_T over 10 km water supply piping is given by

$$p_T=1-(1-0.022)^{100}=0.892.$$

Hence, this damage probability of 0.892 close to 1.0 implies that the function will almost certainly be lost over a length of 10 km.

Electric power supply system

In this case, when one line is broken, electric power can often be supplied with aid of other redundant parallel lines (Fig. 2). Then, the probability of failure for the total system p_T is given by

$$p_T=\{1-(1-p)^n\}^m \qquad (2)$$

where m is the degree of redundancy. Hence, assuming that 100 m is the unit length and that its probability of failure is 0.022, the probability of failure for 10 km single line is 0.892. With one more redundant parallel line, the probability of failure

$$p_T=(0.892)^2=0.796.$$

It is reduced considerably by the redundancy of the system.

5. Conclusions

A consideration has been made of the damage probability of line structures, particularly due to earthquakes.

It was found that most line structures can be represented by a series model in the system reliability model. This is supported by the fact that even a local failure of a line structure usually causes the failure of the function of the whole structure. Line structures represented by such a model were found to have a large probability of failure than that of the respective unit structures. This explains the past evidence that line structures easily lose their function in an earthquake even when ordinary structures are hardly damaged.

It was shown that, in order to improve aseismicity of line structures, a parallel system is effective. However, this would generally be expensive. One practical solution is to reinforce only the relatively weak parts of the line structure. To accomplish this, extensive damage analysis of line structures is greatly desired.

Reference

1) KUBO K. et al., 1975, "Quantitative Analysis of Seismic Damage to Burried Pipelines", *Proc. of the Fourth Japan Earthquake Engineering Symposium*, Tokyo, Nov., 1975 (in Japanese).

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25. 線状構造物の地震時破壊確率

伯 野 元 彦

ここで称している線状構造物とは，幅に比べて長さの長い施設であって，鉄道，道路，水道，電力，ガス配管など都市機能上重要なものを含んでいる．これらが，地震時に壊れると，消火，避難，食料等の物資輸送，情報伝達等，地震時の二次三次災害を軽減させるための都市機能が低下し人命に重大な影響を及ぼすこととなる．ただ，現実の震害を見てみると，これらの施設が地震に対して最も弱い．これは困ったことであるが，その理由を以下のように考えてみた．

これらの施設の機能は，その施設の一部が破壊されると全体の機能がマヒするという特長を持っている．たとえば，鉄道は，一箇所橋梁が落ちれば，不通となるし，電力線にしろ，一箇所ショートまたは断線が生じれば，その変電所管内は停電となる．

Fig. 1 (この例は堤防であるが)のように線状構造物を長手方向直角に切断して，多くの構造物に分割して考えてみる．この1個の構造物の破壊確率を 0.022 と仮定してみよう．つまり 100 個の等しい構造物があった時 2.2 個が壊れるというわけである．この破壊確率は震害としては，かなり小さいものである．ところが，この構造物が線状構造物の1部の場合には，1個でも壊れてはならないわけであるから，全体としての破壊確率 P_T は全体が安全な確率を R_T とすると，

$$P_T=1-R_T$$

と表わされ，また R_T は，

$$R_T=(1-0.022)^{100}=0.108$$

となる．したがって，$P_T=1-0.108=0.892$ となり，この値は非常に大きい値で，ほぼ確実に機能マヒを起こすという結果になる．

このことから，1部の破壊が全体の機能を失わせるような線状構造物の耐震性は，独立構造物よりかなり低いことが納得されるが，その理由は，Fig. 2 に示したような信頼性理論で言う Series 構造物となっているためである．