ASSESSMENT AND MITIGATION OF EARTHQUAKE EFFECTS ON ECONOMIC PRODUCTION

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SUMMARY

Earthquakes not only cause direct damage and human casualties, but also a loss of economic production in the economic sectors directly hit by the disaster and eventually in the economic sectors linked by supply and demand to those directly affected. A method is proposed to evaluate the national economic loss and its potential reduction by strengthening the production facilities and the life line structures. A case study in the San Francisco Bay Area shows loss of economic activity to be of the same order of magnitude as direct property damage.

1. INTRODUCTION

Earthquake Engineering can mitigate the effects of earthquakes in many different ways. Reinforcing structures saves lives and avoids direct property damage, should an earthquake occur. But such strengthening also reduces the loss of economic activity that follows the post earthquake unavailability of labor and the destruction or immobilization of the production facilities. The loss of economic activity includes the loss of production and trade in the economic sectors directly hit in their capital and their labor force (called here the primary economic loss). It also includes the loss of production in the economic sectors linked by supply and demand to those that suffer direct losses (secondary economic loss). For example, the interruption of electrical production may interrupt manufacturing activity.

An analysis of the potential economic losses in earthquakes <u>with</u> and <u>without</u> various measures of earthquake engineering is an important element of evaluation of the benefits of such protective measures. If disaster mitigation policies are to be adopted on the basis of the expected values of costs and benefits, the benefits attached to them should include the reduction of the expected economic losses for the whole nation (Pate, 1978).

The method proposed here permits evaluation not only of the regional economic effects of an earthquake but also of the secondary economic losses that might occur consequently in the nation. The key point here is to relate the total loss of economic activity to the initial physical damage in structures and networks and to the loss of manpower, in such a way that the impact of any reduction of initial damage on the loss of economic activity can be determined.

The final goal is to allocate the resources and efforts of earthquake engineering most efficiently for the reduction of the global loss in earthquakes, not simply the direct losses.

A probabilistic method is used: for each year, in a given region, the different magnitudes of possible earthquakes are considered along with the direct losses that follow. The loss of economic activity (regional and national) is evaluated for each event. [Fig. 1 illustrates the structure of that model].

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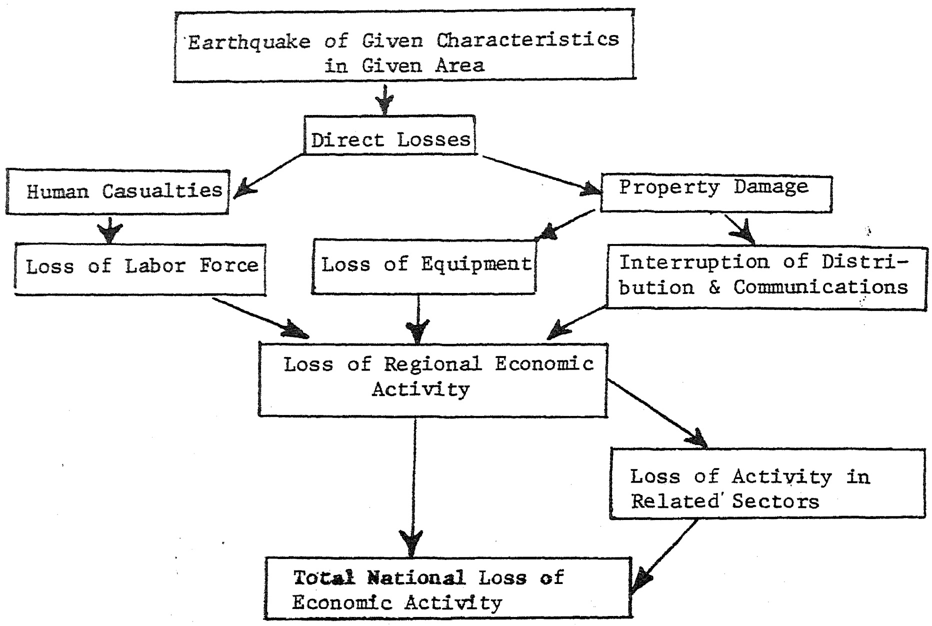

Fig. 1 National Loss of Economic Activity Following an Earthquake

Assuming that one knows the probability that in a given year each magnitude is the maximum of the year, assuming also that the losses of the year in earthquakes are those associated to the highest magnitude, one can obtain a probability density function of annual losses including loss of economic production. In regions of frequent seismic events, one may wish to use a monthly time interval.

For a given building code, it is interesting to evaluate the corresponding expected costs and benefits. In particular, that part of the benefits corresponding to the reduction of loss of economic activity. The financial benefit of a code is obtained by difference between financial losses (direct damage and corresponding economic effects) with and without the proposed codes and its seismic provisions. For the purpose of illustration, a numerical application has been performed for the case of the San Francisco Bay Area, using rough numbers. It is shown that, in that specific case, the avoided loss of economic activity (measured by "added values") is of the same order of magnitude as the avoided damage.

2. DIRECT DAMAGE AND LOSS OF ECONOMIC ACTIVITY

The direct losses are those that occur immediately or shortly after the disaster and are caused by its direct effects (ground shaking, fires, potential failure of dams). In previous works (Paté,1978), a method of computation of direct losses has been developed. The direct losses are thus considered known as a vector of two separate figures: property damage and human casualties. From the total of the former element, one considers now only the damage to commercial and industrial buildings. From the total life loss, one considers only those affecting directly the labor force.

In each sector of the economy (index i) one can potentially attribute to the earthquake:

(1) a loss of manpower ΔM_i for a period of time t_{Mi}.
(2) a loss of capital, equipment and facilities ΔK_i for a time t_{Ki}.
(3) a delay of delivering of primary input, (e.g., raw materials) or the unavailability of input (e.g., electricity) ΔI_i for a time t_{Ii}.
(4) a shift of final demand ΔY_i: needs and preferences may vary after an earthquake; in some sectors one might observe increased demand (e.g., construction) and some smaller demand (e.g., luxury industry).

Each of these four effects can potentially cause a decrease of output of sector i. The final loss corresponds to the dominant of the four: if any of the three inputs is unavailable, the production is halted accordingly [assuming no immediate replacement] and if the final demand for a product decreases the production will have to slow down (see Paté, 1980). The existence of inventory however may reduce the effect on the market of an interruption of production. To compute the potential decrease of output ΔX_{iY} corresponding to the decrease of final demand one can use input-output analysis (Leontief, 1966). The production function of sector i allows computation of the potential loss of outputs ΔX_{iK} (due to the lack of facilities) ΔX_{iM} (due to the lack of manpower) and ΔX_{iI} (due to the lack of input).

The final loss of output ΔX_i in sector i, in the region is the maximum of the four:

$$\Delta X_{iR} = \mathrm{Max}(\Delta X_{iK}, \Delta X_{iM}, \Delta X_{iI}, \Delta X_{iY})$$

Secondary Economic Loss

The secondary economic loss is the loss that occurs in the nation when the primary economic loss causes a decrease of output in the sectors linked by supply and demand to those sectors that have suffered primary economic losses. This occurs when there is no immediate substitution within the nation for those primary losses. For example, if an earthquake in the San Francisco Bay Area destroys part of the electronic manufacturing facilities of the Santa Clara Valley, the industries that use those components for their own production may suffer a loss if they do not find other sources of supply within the country.

The use of the national and regional input-output matrices to compute that secondary economic loss has been discussed previously (Paté,1980). The main issue for each sector is to assess the substitution possibilities and the substitution delays within the nation, and also, what proportion of the loss of output in each sector will affect its supply to other sectors and the final demand for the product.

Again, the method is to consider as binding the most stringent supply constraint: the loss of output in sectors that have not been directly hit, is thus the maximum of the potential losses attributable to the unavailability of each lacking input.

In any case, there is no global result that one can derive from conventional input-output analysis; the structure of each sector has to be considered separately.

3. GLOBAL NATIONAL LOSS FOR DIFFERENT ECONOMIES

Financially, the nation as a whole will thus have lost after each earthquake:

- the property damaged at the time of the earthquake
- the existing inventories that might have been destroyed
- the production during rehabilitation in the sectors directly hit
- the secondary economic loss of outputs in the sectors indirectly reached through temporary unavailability of supply or interruption of demand.

The last two types of losses are limited to the loss of added value once deducted from the market value of outputs the market value of inputs.

The loss of production in earthquakes, and in particular the "secondary loss" depends very much on the structure of the economy, on the diversification of the production, on the vulnerability of the production system, on the flexibility of substitution, and on the development stage of the country.

An agricultural economy is vulnerable through its labor force and its distribution and storage systems. It is important that perishable products (fruits and vegetables) be shipped promptly; it is one of the cases where the secondary impact of disruption of the transportation system could be large. Furthermore, a country whose economic wealth comes essentially from a single agricultural product (or, also, the extraction of a single raw material) and uses that capital to build an industrial force is particularly vulnerable to the unavailability of labor force or transport.

Generally speaking the long term effects of major earthquakes on the evolution of developing economies is difficult to evaluate. The loss of infrastructures is then critical and if the losses are of the same order of magnitude as the national production, rehabilitation of the economy to its initial state depends very much on the international aid.

The losses in an industrialized and diversified economy depend very much on the availability of substitution products. Inputs such as electricity, water, telephone are critical to many manufacturing industries and no substitutes are immediately available. Therefore, the reinforcement of those networks is one of the policies which find still greater benefits in the reduction of the potential loss of economic activity rather than in the reduction of direct property damage. Geographic concentration of some industries in seismic areas makes the related sectors more vulnerable; examples on the west coast of the United States include the electronic industry of the Santa Clara Valley and the aeronautical industry in the State of Washington.

4. A CASE STUDY OF THE ECONOMIC LOSSES IN EARTHQUAKES

For the San Francisco Bay Area, order-of-magnitude losses were computed in the framework of a global study of risk reduction through earthquake engineering (Paté,1978).

For each magnitude of earthquake, the loss of regional and local economy was computed in relation to the damage in commercial and industrial buildings and to lifeline networks, and to the numbers of casualties among the labor force. The destruction of production facilities was found to be the dominant factor in the determination of the regional loss rather than the unavailability of labor force: the proportion of damage among existing facilities was roughly one hundred times larger than the proportion of losses among the labor force.

In the manufacturing sector only, capital loss of added value was found to be around 3 billion dollars for an earthquake of magnitude 8^+, with an additional secondary loss on the order of 2 billion dollars. Table 1 shows those results.

Magnitudes of Earthquakes	Interruption of Activity for damaged facilities	Loss of Added Value in the Bay Area In million dollars	Global National Loss In Million dollars
4-5	6 months	1	1
5-6		7	12
6-7		38	100
7-8	1 year (due to massive reconstruction needs)	450	1000
8^+		3000	5000

Table 1: Potential Loss of Added Value For the Manufacturing Sector in the San Francisco Bay Area Due to Earthquakes [Normal annual added value: $6300 Million per year]

The annual expected value of direct property damage in all existing buildings was found to be on the order of 350 million dollars and the annual expected value of the losses of economic production was found to be around 100 million dollars.

The expected reduction of economic losses through earthquake engineering and building codes was also considered. Reinforcing new buildings will not only avoid property damage but also reduce the potential loss of economic activity. Over 50 years, the discounted expected value of the damage avoided by the seismic provisions of the 1973 Uniform Building Code was found to be in the order of 300 million dollars, a number which applies only to expected damage in buildings to be built between 1978 and 2028 with those techniques. The avoided loss of economic activity caused by damage in the same building population was in the order of 100 million dollars, roughly 1/3 of the corresponding direct damage. (All figures are in 1978 dollars).

One could thus use these techniques to evaluate the desirability of requiring different levels of protection among different types of facilities. Those whose failure would cause large losses of economic activity (e.g., the transportation network) should be reinforced accordingly.

5. CONCLUSION

For an event of large magnitude (8^+) in the San Francisco Bay Area, the losses of economic activity in the manufacturing sector alone could reach at the national scale 1/4 of the total 20 billion dollars of the potential estimated property damage. In an evaluation of potential losses in earthquakes, the primary and secondary losses of economic activity are thus important factors. Reduction of these losses is one of the major benefits of earthquake engineering. In the case of distribution networks for example, whose operation is critical to many economic activities, an appropriate level of engineering should be supplied so as to mitigate the potential economic losses that could follow their failure. Appropriate economic analysis can aid in deciding how to best allocate resources to the protection of such facilities.

6. REFERENCES

Cochrane, H.C., 1974: "Predicting the Economic Impact of Earthquakes", in "Social Science Perspectives on the Coming San Francisco Earthquake. Economic Impact, Prediction and Reconstruction", by Cochrane, Haas, Bowden and Kates. Working Paper No. 25. Institute of Behavioral Science. University of Colorado, Boulder, Colorado.

Leontief, W.W., 1966: "Input-Output Economics", Oxford University Press, New York, New York.

Mukerjee, T., 1971: "Adjusting to Earthquakes: Costs and Benefits", Proceedings of the Conference on Earthquake Risk. Carmel, California.

Paté, M.E., 1978: "Public Policy in Earthquake Effects Mitigation: Earthquake Engineering and Earthquake Prediction", Technical Report No. 30, The John A. Blume Earthquake Engineering Center, Department of Civil Engineering, Stanford University, Stanford, California.

Paté, M.E., 1980: "Evaluation of the Economic Consequences of Natural Catastrophes", Proceedings of the International Conference on Engineering for Protection from Natural Disasters, Asian Institute of Technology, Bangkok, Thailand.