Erosion research and control in Japan

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GENERAL REMARKS

In Japan, intensive research on the phenomena of erosion and erosion control works for preventing or minimizing sediment disasters has been carried out in recent years. This would seem to be an enviable situation at first glance, but it must be said to be an unhappy one too, as the people involved are forced to confront troublesome situations occurring in both nature and society.

Sediment disasters occurred at a rate of about 600 per year from 1976 to 1985 and varied from 200 to 1200 events per year resulting in 842 deaths. The number of missing people is about 60% of all people missing in all types of disasters. The principal causes of these sediment disasters include slope failures (73%), debris flows (15%), and landslides (12%). Moreover, the transformation of stream channels caused by the large quantities of sediment produced from devastated watersheds results in floods in middle and lower river areas.

The Japanese government has invested about 450 billion yen (about $2 billion U.S. at 1985 exchange rate) every year during the 1980's to carry out public works for erosion control. The government founded its public works department in 1877, with a relatively small budget. Laws authorizing erosion control works were enacted in 1897 and projects have developed at an increasing rate thereafter, except in the years during World War II. There have been some changes in the character of the projects. In the late 1800's, the main aim of the projects was the security of inland navigation and irrigation systems. Since the beginning of the 20th century, the main purpose was changed to the control of sediment yield from devastated mountains to prevent flooding of downstream areas. In the 1920's the purpose extended to the protection of mountain villages suffering from sediment disaster. Beginning in the 1960's, rapid growth of the economy and the expansion of urbanized areas brought about a significant increase of serious disasters in urbanized areas. As a result, the public interest in recent years has concentrated to the prevention of sediment disasters.

The primary concern in the research on erosion has changed, reflecting public interests. In the early stages, researchers were interested in the practical problems of collecting and analyzing knowledge accumulated from actual experiences. Then, corresponding with the expansion of the scale of works and increased investment, the demand to attain higher accuracy and reliability became stronger. The research in recent years includes fundamental studies in such related fields as geology, geophysics, geotechnics, hydraulics, biology, and others, in light of a generalized erosion control theory. Thus, research on erosion is essentially an...
interdisciplinary field, and a combination of applied science and practical works.

Therefore, as it seems to be a somewhat complicated matter to explain in a scientific sense, the author intends to consider first the general situation and trends in this field of research and then briefly describe each individual branch of the field, referring mainly to research since 1970.

NATURAL AND SOCIAL SITUATION OF JAPAN

The Japanese archipelago, lying off the east coast of Asia, consists of four main islands (Honshu, Shikoku, Kyushu, Hokkaido) scattered between 123 and 154° E longitude and 20 to 45° N latitude. The territory occupies about 377,000 km² in area and forms a slender landmass that is approximately 2500 km in length from south to north, but less than 300 km in maximum width.

The Japanese archipelago is situated in the Circumpacific Volcanic Zone, and the accumulated energy of tectonic movement is released in nearby areas. Consequently, the land is fractured by numerous tectonic lines, and has steep topography with extensive fragile zones. Volcanic and seismic activity intensify the potential of accelerating erosion in mountain areas.

Japan is situated in a region of heavy rainfall because the continental air current merges with the oceanic air current in its vicinity. The average annual rainfall approaches 1650 mm, and it exceeds 2400 mm in many regions. The land is frequently hit by typhoons between August and October and is also plagued by the locally concentrated torrential rainfall induced by the Baiu front in June and July. It is not unusual for a torrential rainstorm to release as much as 700 mm per day and even 50 mm per hour.

Japan has a population of approximately 118 million and a population density of more than 300 persons per km². Moreover, only 25% of the land is convenient for residential areas, the rest being mountainous (61%), hilly (12%), or internal water areas (2%). About 80% of the total population is living in a restricted flat area; the population density on buildable land is about 1,000 persons per km².

In the 1870's when the erosion control works were started, the population was merely 30 million, and it has increased since then with a doubling in about 50 years until the recent years. The population density in those days was hardly one fourth of the present, and the national economy depended almost entirely on agricultural production. The area of high productivity was located on alluvial cones, valley-bottom plains, and flat lands along river courses, which are susceptible to sediment disasters. The source area of rivers were devastated by continual overharvesting of forests. The socio-economical impact as a result of sediment disasters exerted an important effect on the national economy. Social situations changed rapidly together with the economic growth, and the principal aim of the projects shifted from the security of river utilization to the control of sediment discharge from devastated mountains as part of overall flood-control projects. The antidisaster program was given more importance than the preservation of river utilization because of the remarkable increase in flood...
damage that occurred as a result of increased development of rural areas.

The effort to control local disasters in areas surrounded by unstable mountain terrain started along with the mountain village development program in the 1920's. The remarkable difference between these two programs is that the former intends to control the long-term mean-value of sediment discharge, whereas the latter aims to take measures to cope with extreme sediment discharge events characterized by long return periods. These two programs are essentially the same, but differ in terms of practical techniques, so compatible planning becomes complicated.

Since the 1960's an excessive increase of population density in and around urban areas and the general economic growth induced a striking rise in the price of land throughout the country. It is estimated that the mean price of land in Japan is 30 to 50 times higher than in the USA. The price of $200 per m² is almost a minimum value in the suburbs, and the price of $1,000 to $2,000 per m² is common in more favorable areas. The total cost of all the land in Japan at this price corresponds to the cost of all land in the USA at current prices. This great land value is one of the important reasons that people have an intense interest in the conservation of land and in erosion control problems in Japan. Public investment in erosion control works of about 20 billion yen in 1960 increased by degrees to 45 billion in 1965, 90 billion in 1970, 180 billion in 1975, and it reached 420 billion yen in 1980, about the same level that it is now. Another reason to justify such investment is that the damage caused by sediment disasters exerts an important effect not only directly to a limited area, but also indirectly to the total system of circulation of commodities, transmission of information, and so on. Investment in preventive works has become unavoidable for the stabilization of the overall social system.

This situation has contributed to the progress in research and control measures of erosion problems in Japan, but it must be noted that the techniques for control have become too expensive with respect to the efficiency of investment.

BACKGROUND OF EROSION RESEARCH AND CONTROL IN JAPAN

Although a sediment disaster looks like a flooding disaster, the major difference between them is that a flood passes away after a short time, but the effects of increased sediment yield accumulate through time. When we construct a flood-control dam or improve a river course, the effect of the works against flood disasters continues for a long time, but its function in sediment control decreases incrementally with each event. Accordingly, there is no other way to control sediment disasters other than to control erosion at the source area. It may be an inevitable matter in nature that a mountain is eroded continuously by natural agents and that it is certainly beyond human power to control on a geological time scale. But when we look at it in the time scale of a human life, the rate of erosion is subject mainly to the advance of accelerating erosion in an unstable region. Slope processes do not
occur uniformly on every part of a slope, but are concentrated in some unstable areas affected directly by slope failure or channel erosion. Therefore, an artificial control work at the source area is the only effective means of decreasing the erosion rate and sediment yield from a watershed. A check dam in an unstable torrent is constructed for the purpose of reducing the erosion potential in an unstable area of a slope by means of suppressing the torrent with sediment accumulated behind the dam. If a bare slope is suffering from surface erosion in any place, a vegetative cover is the best way to protect the slope from surface erosion. The cover not only protects the soil surface but also reinforces the soil with a porous root network. These two functions work together to moderate the water cycle and aid soil conservation. Consequently, the occurrence of sediment disasters is connected with the devastation of forests, as we know historically. In Japan, sediment disasters first became a matter of social concern in the 17th century, when the devastation of forests became widespread. Since then, the technology of erosion control developed through the combination of stabilization of torrents and reforestation of bare slopes. An erosion control system based on these principles has been put into practice satisfactorily, but in recent years we have had to reconsider this principle in accordance with changes in the character of sediment disasters.

The disasters caused by slope failures and debris flows began to occur frequently because intensively developed areas encroached on unstable slopes. Earth masses hit these developed areas directly, despite the fact that the maximum distance of the movement is usually only 100 to 1000 m. The traditional method of erosion control is not applicable for these cases because we have to stabilize the unstable portion directly with an artificial structure, or construct a deposition basin and energy dissipation structures along the course of the moving materials. It is necessary to elucidate the mechanism of such phenomena and improve the new construction systems for containing debris movement. It is known that there are 62,272 sites of torrents suffering from debris flows, 72,258 sites of potential slope failure, and 5,777 sites of active landslides, according to an investigation of the government. These include only sites that have more than 5 houses or an important public facility. But it is impossible to carry out an artificial control measure at every dangerous site, even for this limited number of sites, considering the expense and time necessary to complete the work. The control of land utilization is the most important measure, but an overall regulation of use does not fit with social and economic reality because the Japanese economy will have to depend on secondary and tertiary industries in the future, and it will be necessary to allow the concentration of populations in and around towns to some extent. Therefore, we must first provide hazard maps and then arrange warning and evacuation systems as well as construct control structures in the most dangerous sites.

Of course, the projects for controlling erosion in source areas are still the principal concern, and public interest is turning to the execution of direct counter measures in each endangered locality. These are expected to conform to a consistent system of overall erosion control.
GENERAL SITUATION OF EROSION RESEARCH IN RECENT YEARS

Presently, lectures on erosion control are given in the faculty of agriculture at 25 universities, and about 900 students attend these lectures every year. The number of undergraduate students specializing in this field ranges from 100 to 150, and about 50 of them are engaged in research or in the engineering profession of erosion control. About 80 faculty members attached to the laboratory of erosion control in those universities are involved with research and education. In addition, many researchers are doing research principally on erosion in various specialized fields, such as forestry, civil engineering, geophysics, and geology, and also in some governmental organizations, such as the Public Works Institute and Forest Experimental Station.

The researchers join the Erosion Control Engineering Society Japan (ECESJ) and/or the Japan Society of Landslide (JSLS), and most research papers are presented to the general assembly and also published in the proceedings of the society. In addition, considerable numbers of original papers appear in the bulletins published by the faculty or institutes of universities, government institutions, and in the proceedings of societies of related special fields.

The ECESJ was established in 1947 with the "Sabo engineers" as the leading members and has about 3,000 members at present. The society publishes the journal Shin Sabo every two months. At the annual assembly, about 500 members participate, and about 70 papers are presented. The JSLS was established in 1964 as an organization for exchanging information and maintaining solidarity among researchers in various fields related to landslide problems, and has about 2,000 members. The society publishes a journal quarterly, and the scale of activity is almost the same as the ECESJ. As for the societies of related fields, the Japan Society of Civil Engineers, the Japanese Society of Soil Mechanics and Foundation Engineering, the Geological Society of Japan, the Japanese Geomorphological Union, and the Japan Society of Forestry should be mentioned as indispensable sources of information, particularly regarding fundamental research.

Due to the large number of groups that are involved, it is difficult to explain the general situation, so I will explain the general trend of research since 1970 based mainly on the activities of the ECESJ and the JSLS, and then make remarks about important research underway in each individual problem area.

The number of papers presented at the annual assembly of the ECESJ in the first half of the 1970's was around one third of that of the present. It then began to increase through the latter half, and since 1980 it has been about 80 per year. This general trend parallels progress in the leading sciences, and there may be no notable change in the near future.

The research themes that were of greatest interest in the past 15 years are debris flows, landslides and slope failures, hydraulics and sediment transport in torrents, and sediment yield from devastated watersheds. The papers with these themes form about one-sixth of the total. Another third is shared by research on the
forecasting of hazard areas, standards for emergency evacuation, influence of vegetation, practical planning, and others.

As for the methods of research, analyses based on field surveys is the most common, accounting for 50% of the whole. Research based on laboratory experiments concerning channels, slopes, and structures account for 30%, and research based on field observations and the reconsideration of existing general data amounts to about 10% each.

OUTLINE OF RESEARCH IN EACH INDIVIDUAL SUBJECT

Debris flow

Fundamental research is carried out based mainly on analysis of laboratory experiments. In the 1970's, the method for starting experimental debris flows was to enter a mixture of water and soil containing fine materials at the upper end of a flume. In the 1980's, bed layers of coarse grains were mobilized by means of an abrupt supply of water at the upstream end of a movable bed. This change may have been induced by the influence of the report "Mechanism of Occurrence of Mud-Debris Flow and Their Mechanism" by T. Takahashi in 1977. The scheme of flow dynamics is inclined to attach importance to the effect of the diffusive force due to the collision between particles, from a rheological standpoint. In the 1980's researchers are becoming interested in such themes as the effect of grain size distribution (especially the mixture containing fine materials), the reduction of velocity and deposition process in accordance with the change of channel slope and width, mechanisms at the head of debris flows, the transition from mass transportation to individual particle transportation, and others. As for the problems related to the structures for controlling debris flow, the function of such special types of dams (e.g., a wall with deep slits, the beam lattice type, the solid frame type, and a passage with latticed floor) are examined by laboratory experiments and then put into practice.

The analysis of data obtained from field surveys is also an important method of research, and the conditions in zones of debris flow occurrence, passage, and deposition are surveyed just after an incident. Research in this category was reported frequently until around 1980 but has been reported less frequently in recent years because there were few significant debris flow disasters since 1980.

The observation of actual debris flows in the field is another important method. Observations are carried out at several sites, such as Mt. Tateyama (Dashiwara–dani), Mt. Yakedake (Kami–Kamihori–zawa and Ashiarai–dani), River Ura (Kanayama–zawa), River Kiso (Name–kawa), Sakurajima Island (Nojiri and four other rivers).

Observations in Kami–Kamihori–zawa were started in 1970 by a group lead by S. Okuda, 8 years after the eruption of Mt. Yakedake. These observations, in cooperation with the Ministry of Construction, obtained much useful information and made a large contribution to the development of the methodology and facilities for this kind of observation.
Mt. Kitadake, a cone on Sakurajima volcano, became active in 1955 and has erupted about 250 times every year since 1972. Small-scale debris flows have been taking place frequently after heavy rainfalls in areas of deposited erupted materials. Up to the present, debris flows have occurred 239 times in the Nojiri River, 128 times in the Mochiki River, 112 times in the Arimua River, and also in other rivers. There are 15 observation stations, and Nojiri River has the most extensive facilities, involving six video-tape recorders, four sampling boxes, three impact measurement instruments, and more. Videotapes have recorded 14 debris flows between 1985 and 1986, including the range from 300 to 194,000 m$^3$ in total volume, and from 1 to 480 m$^{-1}$ in peak flow discharge.

**Landslide**

Considering the special nature of landslides, the research in this category is divided into two groups: (a) large scale, continuous, and slow movement, and (b) surface slides caused by heavy rain.

(a) Research based on field surveys taken at an individual landslide is the most common, and it accounts for about one fourth of all papers. Among these, the landslides in the tertiary zone in Niigata and Nagano Prefectures take up about two thirds, and the remaining one third is equally divided between landslides in the tertiary zone in Kyushu, in the metamorphic zone in Shikoku and others. In the early stages, interest concentrated on the typical, continuous, slow slides in tertiary zones. It then expanded to include research on landslides in other geologic settings, and this tendency has not changed in recent years. Each landslide has its own character, and this research is intended to understand the special aspects of each individual landslide as a case study.

Research from a geological point of view is almost as common as field surveys, and the characteristics dependent on the geological features are discussed regarding a wide variety of topics. This research tends to emphasize special geological points, so the relationship between physical and geological viewpoints and erosion control research is often less than desirable.

Research based on soil mechanics is the next major field. The estimation of sharing resistance on sliding surfaces is the principal concern, and the character of clay minerals, the residual strength of clay, the rheological character of clay, and the practical method for choosing the coefficient of strength are discussed in connection with this problem. Mostly theoretical analyses of slope stability were presented up until 1975. The trend in recent years has been to produce a simple practical method with high reliability. As to the forecasting of the transition time from slow to rapid movement, the observed data on surface deformation is usually analyzed by means of the theory of secondary and tertiary creep developed by M. Saito in the mid 1960's.

The method and apparatus for field surveys and observation are also important research fields, and related papers are often presented. Almost all of them are intended to improve the accuracy and reliability of existing methods, and there have been few proposals for new methods in recent years.
The research on control work treated mainly the method and the effect of laterally resisting piles, whereas discussion of problems related to drainage works seem to be almost over by 1970.

Generally speaking, field observation and the analysis of landslides are indispensable to the implementation of control works, and so this has contributed to the development of research in this field.

(b) Contrary to the case of landslides, almost all of the research on surface slides treats the qualitative and quantitative characteristics of the phenomena in a specified area, related to topography, geology, vegetation, and rainfall distribution. Only a few papers have discussed individual cases. Regarding a proximate cause of slides, interest usually has concentrated on heavy rainfall; earthquakes were not discussed as often, except in the case of the huge landslide on Mt. Ontake in 1984.

The principal aim of this research is the prediction of potential slide sites and danger zones or the estimation of sediment yield from a watershed. The multivariate analysis and the method for scaling of non-metric factors are applied in this research. Some interesting aspects of this work include interpreting landslides as a geomorphological process in the development of channel systems (by Y. Tsukamoto 1973-78), probabilistic consideration by the assumption of random processes in morphological development (by H. Ohmura 1976-82), and forecasting based on the micro-topography and hydrological conditions of each plot (by T. Okimura 1982-85).

Laboratory experiments using small-scale models are also an important method and have been repeated by many researchers using various conditions and methods. The interest in recent years seems to be shifting from the critical equilibrium condition to the movement of sliding masses after the occurrence of a failure.

Sediment transport and sediment yield

The research on bedload transportation in torrents is one of the fundamental themes in erosion control, and experimental studies of mean velocity, critical tractive force, and sediment discharge in steep channels with rough beds have been attempted repeatedly. Some equations have been proposed and put into practical use to some extent. The problem of suspended sediment transport has received little attention until recently when it came to be noticed in relation to the rapid sedimentation in reservoirs.

The estimation of the change in a torrent bed and sediment discharge in relation to tractive force is carried out through application of a simulation model that consists of the equation for continuity of water and sediment, and a simplified sediment discharge formula. In Japan, the transformation of channel beds in mountain streams is usually strongly influenced by the movement of alternative bars. This movement is, accordingly, given added importance when a laboratory experiment is carried out and the effect is taken into account in the actual planning of control works.

As for the practical application, the effect of construction of a series of low dams and widened or curved portions of channels are
examined by laboratory experiments. Half of these experiments are basic studies of the processes and the rest are an inquiry into actual planning of erosion control works. The function of pass-through type dams are beginning to be examined not only for controlling debris flows but also for bedload movement.

The sediment yield from a watershed is considered from two different points of view: (1) hydraulic estimation of transportation capacity of water discharge, and (2) the geomorphologic point of view. The former has been described above. As for the latter, there is another approach other than the methods described in the research on surface slides, namely, an application of a simulation model for long-term geomorphologic processes. The average value of erosion over the long term can be estimated and is useful for the relative assessment of the erosion potential of a region, but it is not effective for the estimation of sediment discharge as an element in actual planning.

The total sediment yield from watersheds is measured by the volume of deposition in reservoirs, and this is employed during erosion control planning as the long-term average sediment yield. On the other hand, the total volume of potential landslide and movable materials accumulating in torrents is assessed by means of a field survey in a devastated watershed immediately after a disaster. This value is applied during local planning of countermeasures against possible extreme sediment yield events.

**Hazard map, evacuation standards, and others**

Research on the forecasting and mapping of hazard zones for debris flows and slope failures has been carried out by means of multivariate and non-metric factor analysis of data obtained from field surveys and remote sensing. By 1980 this work was generally completed and in 1984 the administrative standard for forecasting hazard zones was presented. The method to estimate the relative level of potential danger of areas was put into practice through this presentation, but the estimation of the range of risks of debris movement is not complete and the problem awaits solution.

Research on the critical conditions for the occurrence of mass movements such as debris flows or slope failures was carried out in order to determine a warning and evacuation standard. To this end, several methods were proposed: consecutive precipitation, rainfall intensity and duration, effective rainfall intensity storing water depth in a tank-model, and others. They were judged in view of the record of past disasters, and although there is no definitive one, each one has both merit and problems. Essentially, the problem is how to estimate the effect of an antecedent rainfall in relation to the rainfall intensity that occurs immediately (1 hr-10 min) before the outbreak of mass movements. Small-scale phenomena are affected strongly by an intense rainfall of short duration, so the forecasting of these events is dependent principally on the prediction of the movement of concentrated cells of heavy rain. Further development of research is expected in this field.

The planning and execution of erosion control works are also important problems, but they are omitted in this report. Another
notable theme is the influences of forests on erosion because the sediment disaster problems in Japan began originally during the reforestation of bare land. Since the 1960's, rapid revegetation of artificial bare land has been required due to excessive development. The money available for the execution of such works has increased considerably, so research on revegetation has become very active and various new methods have been developed. There is no problem establishing vegetation cover on bare land at present, but there is some difficulty with reestablishing the stable succession of a natural ecosystem. Another problem is that the cost has become too high to be practical.