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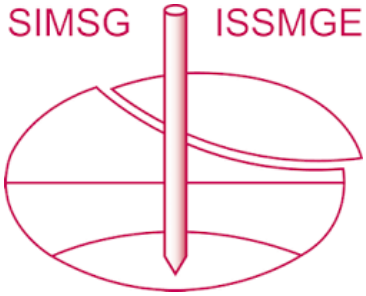

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FORECASTING OF LANDSLIDES AND OTHER MASS MOVEMENTS

PREVISIONS DES GLISSEMENTS DE TERRAIN ET AUTRES DEPLACEMENTS DE MASSES

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SYNOPSIS: Difficulties and weaknesses of the current approaches to landslide forecasting are highlighted and lessons learned through case records are analysed. It is argued that forecasting, in addition to predicting time and place of a landslide event, must also address to the question of runout and its damaging effect on elements at risk. A case record of runout of rockfall is considered and typical results are presented for a sliding mode of runout. Field observations support the results of theoretical analysis.

Need for enlarging the definition of runout to include backward propagation of retrogressive landslides is brought out. For an elongate nature of earthslide, implications of direct hazard, backward propagation and forward runout are discussed in the conceptual framework of an expanding ellipse. Attention is drawn to some cardinal principles and key questions which govern landslide hazard assessment and forecasting.

INTRODUCTION

Landslide events are significantly influenced by diverse factors such as hydrogeology, geomorphology and rainfall. Most factors operate both within and across the time space. Naturally the slopes which stood safe for centuries are unsafe today and those safe today might not remain so even tomorrow not to speak of centuries hence.

In a great majority of cases, landslides are the direct consequences of human intervention. Naturally, a clear understanding of dynamic interaction between human activities and the slope mechanics is essential for reliable forecasting. Where natural forces are dominant and influence of human activity is relatively insignificant, forecasting of landslide events may be possible. On the other hand, where human intervention dominates under uncertain premises, even the best of forecasting methodologies will fail.

There is no crystal ball through which one can see the future and it is therefore imperative that the question of 'fixing the future' with a single forecast be weighed against forecasting of several most probable scenarios.

WHY FORECASTING IS USUALLY DIFFICULT ?

The difficulty of forecasting arises not so much because we lack essential back ground, imagination or hold on factors controlling slope instability but significantly because we neither have reliable information (Table 1) nor the time and money to obtain such information due to wide spread nature of hazardous areas. As a compromise, several simplifying assumptions are made in forecasting, and no forecast could be better than the assumptions that are usually made to deliver it. Yet another reason which undermines reliability is the thoughtless exploitation of narrow forecasting techniques and indiscriminate use of mathematical formulations and 'available' computer softwares, unmindful of the need for integrating the natural world of facts with the social world of values. Then comes the tendency for forecasters to be safe players. This human weakness is not difficult to understand because who would like to err on unsafe side when it would certainly mean an embarrassment to the forecaster?

It is not always easy to understand moves of nature as also foresee a chain of events in their right sequence, not to speak of untangling of knotty relationships between them. Burden of demystifying statistics related to corpus of previous forecasts makes the matter worse.

Extrapolation of the past trends no doubt proves helpful. A clear statement on the practical purpose of a forecast provides a sense of direction. But how could one predict the environmental violence germinating and erupting in human minds and the dramatic consequences of sheer speed, scale and scope of change that follows? One can perhaps take into ones stride the pitfalls of theories developed under different historic circumstances but how can one be certain of making the right choice from the basket full of options? And if that cannot be done, are we morally justified in reading between the lines and in laying prohibitions and in introducing regulations, merely based on our so called judgment?

Table 1

Essential Information : Geomorphological and geological maps to a scale of 1:500; subslope characteristics, shear strength & piezometric variations with respect to the most probable modes of failure; climatic variations.

Desirable Informations : History of slope & of former landslides including changing patterns of landuses; Hydro geological variations; Evapo-transpiration and rainfall data; Changing drainage patterns; deforestation.

Useful Informations : Macro-geomorphology, fossil landslides in the neighborhood; nature and magnitude of human interventions. Slope conversion practices of the past & their impact.

Information as Luxury : Standard Penetration Tests; Pressuremeter tests; wide spread unit weight measurements; drilling much deeper than depth to basal shear.

LANDSLIDE FORECASTS REVISITED

Several professionals have claimed success in forecasting landslides and other massmovements. It is a pity that most of the case records were published after the event. Despite claims of forecasters, it is hard to say if the same confidence level in the forecast existed prior to the event. Takabayama landslide of January 1970 in Japan was predicted by Saito, reported in his paper published in 1979. The forecast of Mt. St. Helens and the prediction of failure of Mt. Toc were published by Voight in 1988, well after the events took place. Of the other reported predictions, slope failures of 18th February 1969 in Chauquicamata mine in Chile, about five weeks in advance of its occurrence, is perhaps the only recorded case of advance action following a scientific prediction. The failure occurred on 18 February remarkably close to the predicted date of 20 February '69. This forecast helped in modification of the mine transportation system and in saving of life and property. Mine production, because of the timely forecast, got suspended only for 65 hours, with minimal production losses.

The above case histories have been closely re-examined by Bhandari(1988) only to infer that such forecasts leave many question marks and draw heavily on past trends forgetting altogether that mere extrapolation of past trends does not make a reliable forecast. The other flaw is seen in the indiscriminate use of rather ill conceived mathematical models which often represent thinly veiled attempts to legitimise arguments. Besides, if the data is fragmentary and unreliable, even the best of mathematical models will not yield reliable predictions. Such attempts may therefore only surface as deceptive evidences of systematic analysis, trasmitting correct signals only by accident. When assumptions are not visible it would be inappropriate to blame people who forget that they even exist. And forgetting of assumptions while interpreting a forecast is the worst of mistakes we can make.

LESSONS LEARNT FROM CASE RECORDS

(1) Models proposed by Saito (1979), Voight (1988) and others based on material characterisation in the tertiary stage of creep are of a very restrictive scope and therefore of a limited value.

(2) The definition of forecasting itself needs amendment. In a real sense it is not enough to predict when and where a landslide will occur. The forecast must include the reach, spread or runout of the slide and its damage potential. Without such a consideration, it would be impossible to save human lives and property.

(3) Proposed relationships between incidences of landslides and rainfall, Guidicini and Iwasa (1979), Brand (1984), Bhandari (1984) and others have series of limitations and forecasts based on them are usually valid for slopes with very well known landslide history, located in areas of heavy to very heavy rainfall.

While dealing with repetitive slides a forecaster usually has the tendency to raise an alarm when rainfall intensity level approaches that connected with the previous few landslide events. Such a prediction may be reliable for the area only if based on synthesis of a large volume of statistical data.

(4) Debrisflows and earthslides usually display large amounts of movement at very high movement rates, spread over weeks and months. At a recent earthslide at Watawala, reported in this paper, the movement rates reached 30 cm - 80 cm per day and yet the train services were operational for quite some time on a track right in the heart of the slide.

Such observations lead to a significant lesson that thresholds of movements, movement rates, piezometric pressures, ground subsidences and heaves etc. need to be fixed in relation with mode of failure and elements at risk.

A NEW CASE RECORD

There is not a single available case record of forecast of a first time landslide in the entire of Himalayan region todate. Based on studies of repetitive landslides and other mass movements in Sikkim, a reasonably good indicator based on the concept of "event co-efficient" was found, Bhandari (1988), but this too had an extremely limited applicability. However in each case analysed, the lessons learnt were significant - one such lesson concerns "runout" as an element of forecasting. Some typical situations involving rockfall are shown in Fig 1.

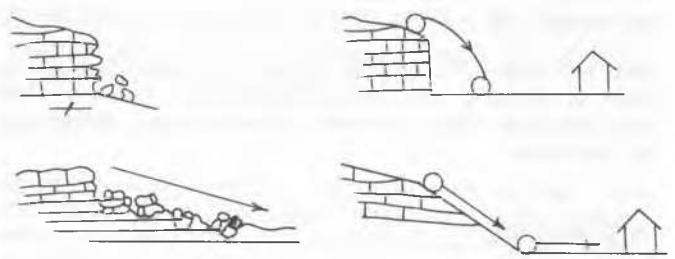

Fig 1: Runout of Rockfalls

Himalayan debrisflows and earthslides are known to travel long distances and destroy whatever comes on their way. The estimates of runout is therefore important. Creation of landslide dams in the Himalayas, Bhandari (1989); filling part of the Nainital Lake by a debrisflow nearly hundred years ago, Bhandari (1989), recurring closer of road at Kaliasaur due to accumulation of debris, Bhandari (1988) all underline the need for estimating runout.

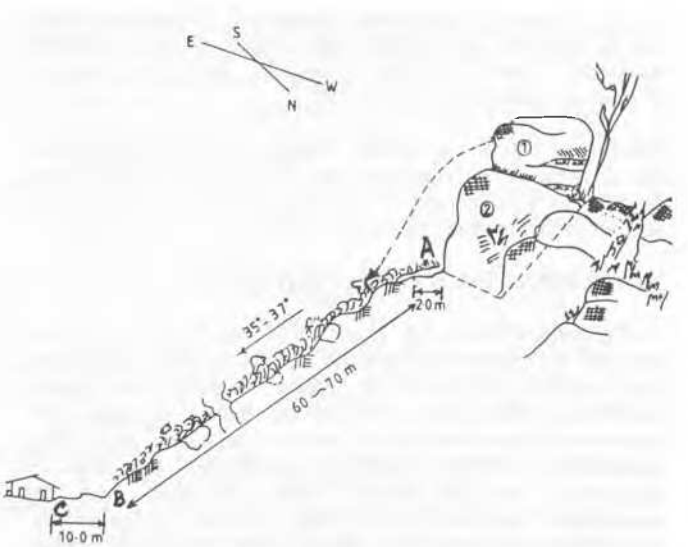

Fig 2 : Rockfall at Dickoya

One of the typical example of a rockfall threatening a human settlement is taken from rockfall at Dickoya, Fig 2. For different modes of rockfall analysed on the bilinear slope ABC (Fig 2), the estimates of runout were made. Typical results of a sliding mode are shown in Fig 3. Good correlation was found between the distance to which a rock would travel and the field observations on actual rock movements.

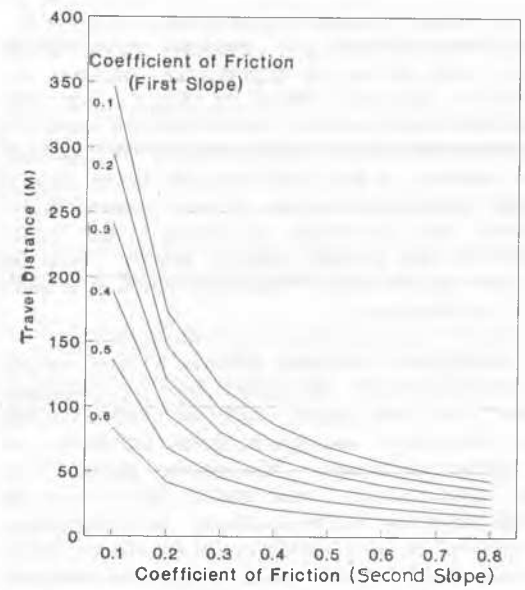

Fig 3 : Runout of Sliding Rocks

A NEW DIMENSION TO THE PROBLEM OF RUNOUT

The meaning of the term deserves to be suitably enlarged to include backward propagation of a landslide due to its retrogressive nature. The slide at Watawala which occurred on 3rd June 1992, following heavy rain serves as a good example. Discrete boundary shears were mapped with clear evidences of tension cracks developing in the head region of the earthslide, Fig 4. Surface movement markers were installed on the boundary shears (Fig 4) and measurement of movements were analysed in relation to rainfall records, Fig 5. These observations not only conclusively established mobility of the earthslide (runout) but also the enlargement of earthslide retrogressively. The impact of this illustrated through Fig 6 in which the elongate geometry of the earthslide is conceptually enveloped by an ellipse, designated as the ellipse of direct hazard. Since the earthslide is active its mobility will affect lower regions and its retrogressive nature will affect upper regions. These aspects of growth are highlighted through expanding ellipses, clearly delineating then of "retrogressive progression" from the zone of "forward runout".

Six cardinal principles influencing Landslide Hazard Assessment and forecasting:
(1) First time landslides are relatively more difficult to forecast than repetitive landslides, if carefully monitored.
(2) The past and present are the keys to the future and when it comes to slope failures, nothing can replace subtle judgment and collective wisdom.
(3) Major causative factors triggering landsliding are identifiable.
(4) Intensity of mapping work can be modulated to the mapping scale adopted.
(5) Landslides can be classified and diagnosed.
(6) Since landslide hazard is strongly dependent on degree, extent and rate of human intervention and it is the hardest thing to comprehend, judge and evaluate, the forecast cannot be free from the ensuing limitations.

Six Basic Questions which aid landslide forecasting:
Q1. Is the area known to be of active landslides or of old landslides or of no landslides? Is the landslide activity of a repetitive nature?
Q2. Do we have statistically adequate and reliable information on slope characteristics?
Q3. Do the geomorphological features and landslide prone deposits of the slide area combine to favour mass movements, under adverse (for example high intensity rainfall) conditions.
Q4. Is the rockfall also feared in the area in addition to probability of occurrence of a landslide?
Q5. What are the sizes, volumes and frequencies of landslides in the neighbourhood? Has any fossil landslide been missed?
Q6. Does the intensity of mapping inputs bear any relationship with scale of mapping and the importance of elements at risk?

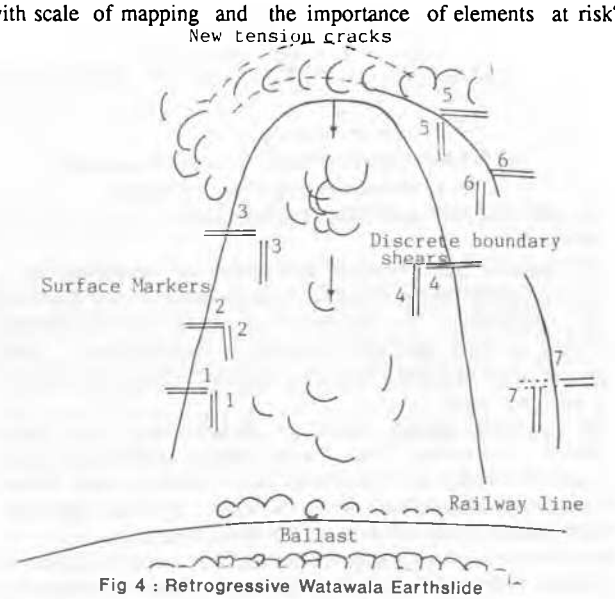

Fig 4 : Retrogressive Watawala Earthslide

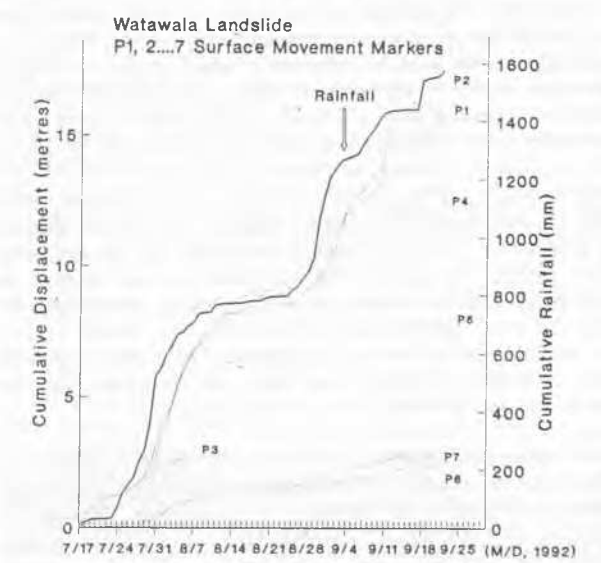

Fig 5: Surface Movements versus Cumulative Rainfall

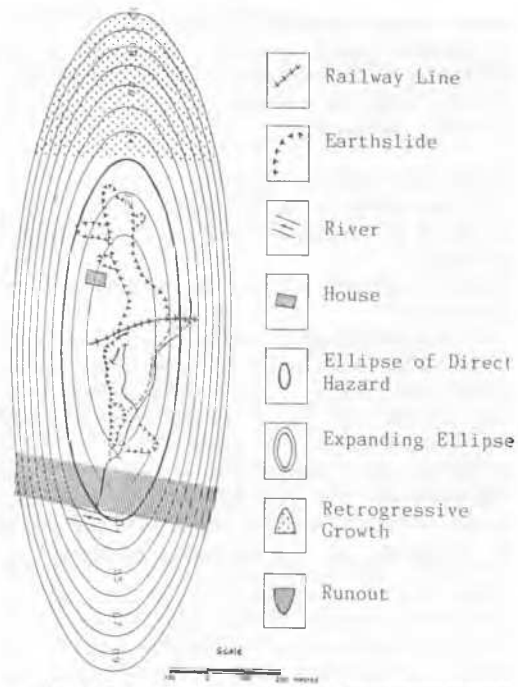

Fig 6: Conceptual Framework of expanding ellipse for an elongate retrogressive earthslide

HOW SIGNIFICANT ARE THE FIGURES AND NUMBERS ?

Most forecasts are fouled by the figures of probability, eg. if there is a 20 per cent probability of rain tomorrow, and if rain will come, then there is a 50 per cent chance of a landslide occurring at such and such location in Hanguranketa. What good are such forecasts even to the professionals, not to speak of a common man.

There are yet another class of professionals who prefer conditional forecasting. They list out factors outside the control of a decision maker and their predictions float on several if'sand but's. It is not always easy to say whether conditional forecasts should deserve preference over definitive forecasts?

Then comes the vexing question of implications of a forecast in situations where stakes are high and consequences (risks) could be disastrous. As for example, consider a forecast with 15 per cent probability of a major earthquake in Assam. If such an earthquake were to occur, thousands would perish and tens of thousands would be rendered homeless. How should then the government handle such a forecast? If they neglect it and if the earthquake does occur as predicted, the inaction on the part of any government would be branded as its callous attitude towards people. If the government acts fast and spends public funds on preventives and nothing happens, it would be charged for unnecessary spending, when more important matters await in the queue. And will not the swift action on the part of the government stir the imagination of the people, compound their fears and even halt the pace of progress and development in the face of a gloomy forecast. Land prices in the area may come down, migration of people may begin and attention from real issues may get diverted.

Count down of a hazardous event and the human psyche:

Let us take the example of forecasting of landslides following an earthquake based on duration of precursory changes in velocities of P & S waves. An earthquake of magnitude 6 could perhaps be predicted a year in advance and that of magnitude 7, as many as 6 years in advance. If that be done, several difficulties might arise. The first warning is likely to be vague, or without knowledge of probability of occurrence.

The scenario developed by Eugene Haas and Dennis Mileti (reported by Aaraonson, 1977) refers to a prediction three years ahead of an earthquake of magnitude 7.3, involving an urban area of California. News of the prediction first leaks to news media through seismologists in the form of evidence that show a 25 per cent chance that such an earthquake will occur at the designated time. Within a year, property values fall, new constructions halt, and the cost of earthquake insurance in the region becomes prohibitive. When the prediction gets refined and an officially release appears in the form of a warning that there is a 50 per cent chance of an earthquake of magnitude 7 or greater occurring in two years' time, the picture drastically alters. Many families leave the area, business houses close and unemployment rises. Just before the expected quake, residents remaining in the area stockpile essential supplies. Areas down stream of dams get evacuated. Troops are moved in to prevent anticipated civil disturbance.

Naturally, a disruption of normal life over a period of years, produces high economic and social costs, for a situation in which there is an even chance that there will be no major earthquake. More urgent warnings, on shorter time-scales - even for rather smaller earthquakes - raise obvious problems if they may cause a panic reaction, mass exodus from a city or cities with resultant disruption of communications, and opportunity for the unscrupulous to take advantage of the chaotic situation either through straightforward looting or arson and provocation of mob violence. These factors and more ought to be looked at very closely, knowing well the sensitivity of the issue involved.

CONCLUDING REMARKS

A holistic approach to forecasting is essential if the aim of the forecast is to save lives and property. The consideration of runout and damage potential naturally deserves to be considered alongside prediction, of the time and place of occurrence.

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