The human dimensions of dam safety PART ONE

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In this two-part article, the authors assess traditional approaches to dam safety, point out that the human aspect of safety and the effect of disaster has been seriously neglected, and suggest measures to improve this state of affairs

DAMS ARE BUILT to serve the needs of man and his environment, which together comprise the human society. In order that dams and reservoirs can be built, and be beneficial to society as a whole, it is necessary to identify the socio-economic priorities along with the characteristics which influence their overall safety.

It should be realized that an approach to the safety problem cannot be merely techno-economic, it should be subjected to rigorous socio-economic analyses in order to rationalize and improve the existing criteria for optimal design and operation of dams.

From such analyses will evolve design criteria which might considerably reduce the failure probabilities by developing new concepts. It could also reduce the existing social antagonism toward dam failures to a great extent.

It is rather unfortunate that dam designers have rarely recognized the importance of this approach. Often they are too engrossed by the economic factors and the technological challenges that are inherent in the decision-making process. Hence, a discussion of the behavioural aspects of dam disasters, that have been generally neglected so far, should be of considerable interest to all water resources systems designers.

The difficulties involved in the evaluation of physical safety of dams are enormous, but this point obviously has to be considered in the overall problem of dam safety. The design criteria for dams have changed substantially over the years, ie. the importance and the existence of uplift pressure was realized only toward the end of the 19th Century; grouting procedure has come into being within the last 40 years; and the use of foundation drainage is of still more recent origin.

But in spite of this progress, the present techniques of dam design have too many assumptions, approximations and unknowns, and they make dams far from immune to failure.

The cumulative probability of dam failure is a very important factor that should also be considered carefully. The growth of dams during the post-1900 period has been fantastic. For example, in the USA alone, the number of completed large dams (over 15m in height, or between 10 and 15m with a storage capacity in excess of 100 000m^3) has increased from 116 in 1900 to the staggering figure of 2635 in 1962.

As many more dams are going to be built in the future than those that are going to be out of use, the problem of dam failure is bound to get worse on a collective probability basis.

This is a fact that has up to now received very little attention among the water-resources planners[1,2].

Failures of dams and reservoirs that cause loss of life and damage to property, invariably attract considerable public attention[3], and justifiably so. This should therefore inspire the government agencies concerned to take advance safety measures, and also to support research projects to investigate corrective and protective actions[4]. Table I shows the estimated cost of property damages resulting from a few selected dam failures.

In general, it may be said that dam disasters involving loss of private and public property, are of direct concern only to the owner of the dam and the parties that suffer the damages. The losses become a serious public concern when the owner has no means to compensate them.

Losses due to dam failures—as indicated in Table I—have often proved to be quite substantial even to the highly developed nations, and may well prove to be disastrous for the developing nations.

Table II shows loss of lives from some selected dam failures. Such catastrophic loss of life and damage to property become a direct concern to the public, and hence to the government. The role of the government in the overall supervision of dam and reservoir safety has therefore been well recognized in modern times.

Water resources development and dam disasters

Water resources development by the construction of dams, dykes, embankments, and reservoirs, is probably as old as our civilization, but its full impact on civilization, from ancient times to the present day, is yet to be fully understood[5].

Far more unsatisfactory, however, is our understanding of the socio-cultural consequences and implications of dam disasters. While water has been worshipped as a god, it has also been hated as an evil force whenever it has wrought devastation and destruction.

The importance of an adequate warning system, with pre-planned rescue, evacuation and other post-disaster operations, was clearly demonstrated by the Baldwin Hills disaster, in California. Only three lives were lost, even though the total property damage approached $50 million.

In contrast, the Oros dam disaster in Brazil had high death tolls with comparatively little property damage because of inadequate and unsatisfactory warning, evacuation and rescue systems.

At the Vajont dam disaster, in Italy, the telecommunication lines were destroyed by the impact of the waves that overtopped the dam. Since such an event was unforeseen by the designers, the first warning came only when a policeman noticed the flood water, a few miles downstream.

Other warning signals, ie. minor earth slides, uneasiness of local animals, etc, were ignored by the authorities, who were satisfied with their engineering analyses that indicated the stability of the earth mass which later slid with such catastrophic consequences.

At the Oros dam, on the other hand, advance warnings were issued which enabled nearly 16 000 people to escape[6], but even then some 1000 lost their lives.

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Thus, it can be seen that current design practice and operation of the warning and other associated systems leave much to be desired.

Garb and Eng, in their disaster handbook[7], draw significant conclusions from a comprehensive study of different types of disasters, including dam failures. They suggest that:

(i) Studies of major disasters reveal that about 95% of the casualties could have been prevented;

(ii) Effective disaster operations depend on how well each individual and each organization does its own job, as well as allowing others to do theirs;

(iii) Very little opportunity is available to test, improve and innovate methods of handling disaster problems.

Little, if any, attention has been paid so far by engineers responsible for designing dams to devise means to counterbalance the risks thus created. Our knowledge of casualty prevention, especially due to dam disaster *per se*, is highly inadequate. There is an acute scarcity of data on such disasters and research findings on the individual and organizational behavioural aspects during such disasters are few and far between.

Saventhem and Muller[8] have cited some interesting statistics to emphasize the magnitude of losses due to dam disasters. More than 5000 people have lost their lives in embankment failures during the past 20 years, and the estimates of total property damages range between $250 million and $750 million.

With more than 10 000 large dams currently in existence, comprehensive insurance for dams may prove to be an economically feasible concept, provided it is universally seen as a common need.

Ironically, a committee set up by the International Commission on Large Dams (ICOLD) to study the overall problem of dam safety and insurance, is currently (late-1970) inactive because of lack of funds[9].

Community and dam disasters

Quarantelli and Dynes have suggested that disasters provide the context in which significant human dramas are revealed[10]. Yutzy considered disasters to be collective phenomena that upset patterned social arrangements of communities[11].

Generally, most communities organize themselves around traditional functions, ie. participation in production-distribution-consumption processes, socialization, social participation control and mutual support, that are relevant to living in a particular situation.

When the disaster threatens the achievement of valued ends of these functions, the adaptive response pattern, called "the emergency social system", swings into action[12] with a new set of priorities due to high demand for certain goods and services, and the inability of the affected community to produce all or some of the goods and services.

Thus a typical ordered set of priorities that evolves as the organizational goal during a disaster emergency could be the following:

(1) Preservation of life;

(2) Restoration and maintenance of essential services (transport and communication for disaster operations);

(3) Maintenance of public order (safeguard of property and control of crowds);

(4) Communal use of all property; and

(5) Maintenance of community morale through mass media and emergency communication systems.

The organization of the priority system is, however, dependent on two characteristics—disaster agent and community.

There is little doubt that communities that undertake prior planning and preparation for disaster will develop an effective emergency action more quickly than others. Yet, research endeavours to seek the inter-relationship between such variables in catastrophic dam disasters have long remained a neglected subject.

Some of the disorganizing effects of disasters are well-known. For example, Dynes[13] has explained how disasters tend to organize a community. The presence of an effective organization plan has reduced losses from dam disasters substantially in the past, and consequently, increasing attention is currently being paid to better supervision of dam safety.

Yet, little research is being conducted to develop more meaningful warning and rescue operation systems.

It is, therefore, surprising to note that even though catastrophic consequences of potential dam disasters have been recognized long before the twentieth century, research on their behavioural implications has been practically non-existent.

Only recently, have preliminary studies on the Vajont and Baldwin Hills disasters been conducted by the Disaster Research Centre of the Ohio State University[14], and more scientific and in-depth studies of the human dimensions of dam disasters are highly desirable and badly needed.

Complete absence of public participation in the choice and selection of safety criteria for dams may have contributed to this rather sad state of affairs. Suitable political systems and institutional arrangements do not exist to rectify this situation.

Admittedly, ICOLD has made commendable efforts to establish a common international standard for evaluating dam disasters, and thereby establish criteria for comprehensive evaluation of dam safety[15]. The effort, however, may not achieve an appreciable measure of success due to

Table I—Estimated damage due to some dam disasters

Dam	River	Country	Year failed	Damage (million US$)
Mill River	Mill	USA	1874	1·0
Lynde Brook	Lynde Brook	USA	1876	1·0
Johnstown	Little Conemaugh	USA	1889	100·0
Brokaw 2	Wisconsin	USA	1938	0·7
Malpasset	Le Reyan	France	1959	68·0
Babii Yar	Dneiper	USSR	1961	4·0
Baldwin Hills	Owens	USA	1963	50·0
Mayfield	Cowhitz	USA	1965	2·5
Wyoming	Sybille Creek	USA	1969	1·5
Pardo	Seco de Frias	Argentina	1970	20·0

Table II—Deaths following some major dam failures

Dam	Country	Date of disaster	Lives lost
Vajont	Italy	October 9, 1963	3000
South Fork (Johnstown)	USA	May 31, 1889	2200
Oros	Brazil	March 25, 1960	1000
Puentes	Spain	April 30, 1802	600
Saint Francis	USA	March 13, 1929	450
Malpasset	France	December, 1959	421
Hyokiri	Korea	July, 1961	250
Quebrada la Chapa	Colombia	April, 1963	250
Babii Yar	USSR	March, 1961	145
Veg de Tera	Spain	January 10, 1959	144
Pardo	Argentina	January 6, 1970	25
Baldwin Hills	USA	December 14, 1963	3

the differing natural, social and economic factors of the countries involved[16]. Dickerson suggests[9]:

> "It will be evident . . . that all engineers concerned with the branch of engineering science relating to dams put as their primary objective the overall safety, not only of the structure, but also of the public directly affected by the existence of the dam and reservoir."

He further suggests that some form of control at government level should be universal for all dams and reservoirs. Hence, it may be argued that effective public participation could make a substantial contribution to improve dam safety problems.

Informed public opinion is thus a necessary ingredient for better safety measures. A safety-conscious public will not only demand safer dams but will also be prepared to pay for the improved safety measures. With full public support, it is quite likely that the present criteria for safety and economy of dams will substantially change for the better.

It seems that this aspect has seldom been realized by the policy-makers and legislators entrusted with decision-making, and much less by those directly responsible for dam and reservoir management.

Examples of public reaction

Following the disaster of the Spanish dam, Veg de Tera, in January, 1959, civil and criminal proceedings were initiated against ten engineers. Four of them were convicted by the lower Court, and the conviction was later appealed. Even though the judgement may have come as a surprise to many engineers[17], it can hardly be denied that public pressure was largely responsible for the initiation of the charges.

Later, in the same year, failure of the Malpasset dam in France led the authorities to charge its Chief Engineer, Dargeou, with homicide and injuries through negligence in connection with investigation, construction and operation of the dam.

The court found him not guilty[18] since "he merely controlled and supervised so that Coyne's (the designer) directions were strictly observed . . . the whole of the technical responsibility laid with Coyne and his office".

In spite of the serious differences of opinions among experts about the failure hypotheses (one considered failure to be unforeseeable and the other to be a result of sheer negligence), the response of the society to the whole affair was one of extreme disappointment.

Similar public reactions were noticed after the Vajont and Baldwin Hills disasters, and yet there has hardly been any comprehensive study to assess the full implications of the changing community responses to dam disasters. Some improvements of the safety standards made so far do indicate an indirect subjective appreciation of the public concern.

However, unless an in-depth study is undertaken, it would be difficult to develop a comprehensive dam safety approach commensurate with the needs and desires of the public.

Some consultants have pointed out that their clients do not respond favourably to improved safety standards, especially when cost factors escalate. It has been suggested that they may even lose some of their clients due to such actions. The truth underlying these claims cannot be entirely ignored.

Sherard et al[19] have also noted this problem. They suggest that the consultants should emphasize the optimal safety measures to their clients during all stages of design, construction and operation. Thus, an assessment of the consultant-client relationship, with regard to safety requirements, should prove to be useful mission-oriented research.

Necessary studies

Unfortunately, none of the studies mentioned so far have been undertaken—a fact which clearly indicates that much remains to be done to develop, as well as adapt, new techniques in dam safety which can satisfy public needs and desires.

It should be realized that even though the cost implications of improved safety provisions are clear, the benefits are difficult, if not impossible, to quantify. The data available at present is not adequate to make a meaningful assessment of the reduction in the frequency of dam failures due to such measures.

Also, in the absence of sufficient data and techniques for quantification of the socio-cultural impacts of dam disasters, the benefits accrued will have to be considered secondary in terms of the usual cost-benefit-analyses.

Nevertheless, in human terms these benefits are very real, primary and direct, and the dam safety problem should be handled in such a manner that a significant percentage of the population is not left overwhelmed and disenchanted. Public participation in the decision-making process and in the sharing of benefits and costs will surely improve the present situation.

Besides, it is not a satisfactory practice to neglect the probable disaster costs in the cost-benefit analyses, however difficult they may be to assess. The seriousness of these costs has seldom been realized due to lack of effort to collect relevant data and to assess the probable disaster costs.

There is little doubt that such assessments could provide a better approach to the problems of dam safety.

Generally, planning of water resources projects takes several years, and it is not always undertaken solely for economic reasons[20]. Dam safety investigations, with special emphasis on the socio-economic aspects, should form an important part of the planning process, and thereafter the management should continue to evaluate these factors during subsequent construction and operational phases.

Economic and recreational growth resulting from the creation of a large reservoir is likely to increase the demand for higher standards of safety. The managers and decision-makers should recognize this need and act accordingly in all phases of their activities.

The dynamic nature of the economy and the society necessitates a dynamic safety model as a framework for the establishment and review of dam safety standards. Lack of recognition of this dynamic nature may be responsible for the phase lag between demand and supply; and it could explain to a certain extent the cause of the existing discrepancy.

Public perception of dam safety

Dam designers and managers have not made significant efforts to evaluate the public's attitude and perception of dam safety problems, and the social consequences of dam disasters. There has not been any systematic study to establish the relationship between public perception and the risk of failure so that different measures can be effectively used for reducing disaster potential. This is probably the major reason for the absence of suitable design criteria for safety that are compatible with technical know-how and public attitudes.

Evaluation of social factors, as related to the safety of dams, is urgently needed for better design, and it should be based to a great extent on public perception of the problem and demand for action. These, in turn, would depend substantially on the efforts of dam designers and managers to educate the public[21], who have already indicated grave concern about such events.

The main aim, therefore, is to win public support for a programme that would minimize the risk of dam failures and their adverse consequences. Successful operation of such a scheme is very likely to have a feed-back effect, which will further advance overall safety programmes. Lack of public participation in this field has, to a certain extent, been due to the past authoritarian decisions that have sometimes jeopardised safety in order to achieve what may be termed as "irrational" economy.

Ibsen and Ballweg have suggested specific methodologies to study public perception of water problems[22]. The risk and probability of a dam disaster should be carefully considered by water-resources planners. Slow realization of its adverse potential by engineers and complete neglect by social scientists have so far rendered dam safety measures rather lop-sided and ineffective.

Research on socio-cultural systems and interest group strategies, vis-à-vis dam safety, is expected to have considerable influence on the development of realistic techno-economic criteria for safety and economy.

Thus, a change of approach will certainly be advantageous to the dam technologists, their owners and the public, and it may eliminate disasters that can occur through undue emphasis on economic decisions, ie. the Schoelkoff incident[23].

It should also go a long way towards eliminating some of the public distrust of professionals that has resulted from the failures of the Baldwin Hills, Khadakwasla, Malpasset, Vajont, Veg de Tera and other dams.

Some of the information available on a few selected dams that have failed will be summarized later in this article, together with a critical appraisal of how it may be used effectively to build safer dams in the future, but much remains to be done to conduct a comprehensive investigation of dam disasters as such.

Rayner has prepared a bibliography[24] of about eighty items that attempt to conceptualize or formulate disaster theories and models. These models can be used to develop a systematic logical framework for rational analysis and design, and to devise improved safety criteria.

As inventories of empirical data on dam disasters are not readily available, it may be useful to utilize relevant experiences from other different types of disasters to reinforce the information already collected. Due to the absence of any comparative study and research, based on different types of disasters, it is, however, difficult to forecast the effectiveness of such knowledge in the design and operation of dam and reservoir systems so as to maximize economic benefits and minimize human suffering.

A socially acceptable solution to these problems is urgently needed, and it is therefore necessary to initiate programmes to determine public concern for dam disasters so that efforts can be made to devise a solution that could merit the best public support.

However, it should be realized that the best public support is a highly controversial criterion, and is a relative term. Hence, the safety criteria will in all probability differ with location, time horizon, cultural status, and other pertinent variables.

A more comprehensive study of the problem is possible only if considerable data are collected, and empirical studies are made, so as to increase our present understanding of the problem.

Dynes has suggested[25] that a comparative study of community response to stresses like flood disasters and water-pollution problems should be undertaken so that the priorities, perceptions and structural adaptations in differing stress situations and community structures can be identified and evaluated. It would also be necessary to assess the value of similar investigations for dam disasters.

The magnitude of expected benefits will undoubtedly justify such research, especially for the communities that may be directly threatened by dam failures, since disaster planning in most cases seems to be almost non-existent.

Vajont dam

On the night of October 9, 1963, the Vajont dam was overtopped by a 330ft flood wave. Some 3000 lives were lost—the heaviest loss ever recorded due to a dam disaster. It was caused by an unprecedented landslide into the reservoir that was almost full. A preliminary sociological study of the disaster has been carried out by Quarantelli and Haas[21], and the major findings are summarized herein.

A noteworthy characteristic of the disaster was that the number of dead was nearly 30 to 40 times the number that were injured. It had a serious effect on the post-disaster operations, ie. intra-organizational strains due to limited number of personnel (physicians, rescue party, etc) and supplies (medical supplies, blankets, bedding, etc) needed.

Public criticism of organizational efficiency due to the apparently-slow rescue operations (very few survivors were left to be rescued), and use of manpower and shovel instead of mechanical equipment for debris clearance and digging for bodies.

The organizational mobilization, based on standard operating procedures, was found to be rather unsatisfactory. Many thousand hospital beds were arranged, but the number of injured survivors was only 86, and the relief supplies far exceeded actual demand. It probably indicates poor communication between the field operations and the planning unit.

Smaller earth slides in the reservoir area, recorded prior to the mishap, were considered insignificant by the experts responsible for the maintenance of the dam. The slides were probably the early indications of the forthcoming catastrophe.

The post-disaster weather conditions were ideal. There was no rain, even though heavy rain had occurred prior to the disaster, and this eliminated several problems which would otherwise have made the problems more complex. (It is essential that planning of post-disaster operations should consider adverse weather conditions.)

The general tendency of all the organizations participating in the rescuing operations was to concentrate on the "ground-zero", the point of maximum devastation. However, it was soon evident that the least assistance was needed there because of total devastation. The reasons for this anomaly were as follows:

(i) Generally, the need for relief is proportional to the intensity of devastation, but such a functional relationship ceases to have much validity in the case of total destruction;
(ii) The disaster headquarters were located at the "ground zero" instead of being on the periphery of the disaster area;
(iii) The approach to the area was simple, as it was connected by a transport route, and it provided opportunities for ample publicity by the mass media.

The co-ordination of the disaster operations was unsatisfactory and necessitated further planning and improvement. There was also a lack of inter-organizational understanding which resulted in public criticism.

There were several reasons: an unsatisfactory and inaccurate communication system; poor initial feedback; ineffective inter- and intra-organizational communication; somewhat unrealistic planning by adherence to the standard operating procedures; unsystematic diffusion of the casualty picture; and inadequate information screening that resulted in inaccurate statements and requisitions.

The establishment of a Disaster Information Centre would have alleviated many of these problems.

There was also considerable ambiguity in the relationship between the Civil and the Army authorities which prevented systematic rescuing operations.

The Civil authorities considered the Army to be in full control of the situation, whereas the Army publicly denied having superseded the Civil authorities. The Civil authorities were also reluctant to take an active part in the post-disaster operations. Such an attitude was probably caused by several factors.

Firstly, the dam was built in the face of opposition from the local inhabitants who were apprehensive of the rock-slides from Mount Toc.

Secondly, the Communist Party newspaper predicted the disaster in 1959, and was immediately criticized for purveying false propaganda.

Thirdly, the catastrophe created a distinct possibility of the reorientation of the political affiliations among the partisans in the Italian pluralistic society.

Fourthly, there was a serious political controversy over the nationalization of the private company that built the dam. Finally, the Italian President was greeted by a hostile crowd in Longarone.

Thus, the disaster become something of a "political football". The Civil authorities kept away from the post-disaster initiatives, and the Military also could be included in this criticism.

A major problem arose from the cultural values and norms regarding the handling of the dead. Secondary threats (though somewhat remote) were perceived after the disaster. They included the possibility that the dam might give way and cause another catastrophe; impending epidemics; possible poisoning of the river water; and further earth slides due to the backing-up of water behind the "slide dam".

From this account, it becomes evident that there is a clear need for proper planning of post-disaster operations with due regard to the various social, economic, political and environmental factors. Planning based on previously observed disasters, along with simulation and laboratory studies, provides a promising strategy for the safer design of dams as well as formulation of effective procedures for disaster operations[13].

Very little information from past disaster experiences has so far been used to improve the safety of dams and reservoirs. Such information, if available, should be useful in further studies of dam safety. In fact, all project reports on the major reservoirs with possible high disaster potentials should include a comprehensive study on the probable disaster patterns and consequence.

Such descriptive analyses could form the basis of the classification of dams, with different degrees of safety requirements. Research endeavours to develop analytical tools that would include socio-economic factors to assess safety criteria should therefore be encouraged.

Serious public disapproval of the Vajont failure resulted in the initiation of legal proceedings against 11 Italian engineers who were charged with manslaughter and negligence of duty. The opinions of the experts on the causes of the Vajont disaster are contradictory. One group concluded that it was due to sheer negligence, whereas the other suggested that at the present state-of-art, the slide could not have been foreseen.

Apparently, both conclusions are highly subjective and involved what has been called a judgment dimension[25]. The fact that some of the best experts of our time were involved indicates that the limitations of our present knowledge are a prime cause of the disasters.

It is suggested that the most important aspect—which the present dam safety programmes lack—is a scientific and socio-economic plan to reduce all probable disaster losses. An effective approach should therefore develop from studies and analyses of the human dimensions of dam safety.

Baldwin Hills dam

When the Baldwin Hills dam disaster occurred on December 14, 1963, only five lives were lost and 27 were injured, but the property damage was estimated at $50 million. Some 16 500 people lived in the disaster area, and most of them were safely evacuated. It is a heartening commentary on the excellence of the warning and evacuation systems, as well as the timely detection of the signs of the failure.

The caretaker noticed an alarming pencil-thin crack on the north-east face of the dam at 11.15am. The California Department of Water and Power, after careful investigation, alerted the Police Department around 1.30pm.

The time lag between the first signs of the possible failure and initiation of the warning (which began at about 2.00pm) was still high, and a more efficient system of engineering investigation during emergencies is necessary and should be developed.

Effective use of helicopters and visual aids during emergency inspection may reduce the time lag to a reasonable period. Warning and rescuing groups should be alerted soon after the first signs of danger are noticed.

The Police Department, with the assistance of other services, did an excellent job of warning and evacuating the people between 2.00pm and 3.30pm. Had the operation started earlier, it may have been possible to rescue several injured persons.

The use of cars, motorcycles, helicopters equipped with public-address systems, door-to-door warning, radio and television appeals, road blocks for efficient evacuation, and effective perimeter control by the police department contributed significantly to the surprisingly small number of casualties.

Some idiosyncrasies were noticed during the disaster operations. Many doubted the authenticity of the warning as they were unaware of the close proximity of the dam. Some, apprehending no danger between the warning and the impact, went back to retrieve their belongings, and a few even considered the anticipated disaster due to the dam failure incredible because they lacked visual experience of such events.

Some tried to escape on foot or in automobiles when the flood waters had reached the streets, were trapped and died.

These observations lead to one simple conclusion: there is a need for systematic education of the people living under such risks[22]. The mass media can be effectively used to educate the public, and any information system devised may have to be used frequently.

The initiative for such studies should come from the engineers responsible for the design and supervision of the dams. No one can better assess the disaster potential of a dam and its probability than those who are charged with the responsibility of design and maintenance. The assessment of potential patterns of dam failure, and the consequences of such events will therefore constitute useful research.

Such investigations and proper advance disaster planning systems would certainly minimize failures and the losses arising from them.

It is often contended that research and mass-media publicity of possible dam disasters may have the undesirable effect of reminding people of the risks under which they live. It is suggested that it is preferable to live with the unpleasant awareness of the risk, rather than exist in a state of happy ignorance which may finally be shattered with tragic consequences.

It should be noted that the Police Department was the key organization of the Baldwin Hills disaster operation, which consisted primarily of evacuation, perimeter control and protection of public and private property. Some of the essential organizational features, such as inter-organizational communication, co-operative decision-making and close co-ordination of the various field groups, were achieved with remarkable success in the disaster operation.

A methodology to assess community reaction to water-resources problems has been suggested by Dynes[26]. Disaster research, however, is of comparatively recent origin. Some preliminary work on the sociological aspects of dam disasters has been carried out at the Disaster Research Centre of Ohio State University, by Anderson[27] and Quarantelli and Haas[21].

Little, if any, research has been conducted on how the engineers responsible for building and managing dams can effectively serve in the disaster operation teams. Necessary planning techniques for effective utilization of engineering manpower in such circumstances is badly needed.

Unlike the Vajont incident, no charges were brought against the engineers responsible for the design, construction and operation of the Baldwin Hills dam, even though a safety inspection had taken place a few months before the failure. The tragedy brought medals for many[28], and justifiably so: the work of the engineering staff in the imminent pre-disaster period was commendable.

The investigation commission found that earth movement was the cause of failure of the reservoir lining and the consequent collapse of the dam. Further studies revealed that natural gas withdrawals from the Inglewood oil field nearby were responsible for excessive subsidence (about 9ft vertically), and were the primary cause of the disaster.

The city of Los Angeles and its Department of Water and Power, which owned the dam, sued the nine oil companies involved for a total of about $26 million[29]. Later, the suit was settled out of court for about $4 million[30].

However, it should be noted that the designers of the Baldwin Hills dam were well aware of settlements that had occurred in the area prior to the dam's construction[31,32], and also of the activities of the oil companies. The prediction of extraction rates could easily have been obtained, but it would not have helped much as no correlation could have been established between settlement and oil extraction.

Moreover, technology had not advanced far enough at that time to design dams which could resist gradual foundation movements of 2ft horizontally and 9ft vertically.

Many lessons can be learnt from the Baldwin Hills failure. Effective supervision, warning and rescue systems can effectively minimize the damage, if not the failure itself. It also demonstrated the need for public education for successful post-disaster operations.

Efficient planning and design of pre-disaster engineering operations also deserve attention. The development of new techniques for earth-dam design to resist foundation movements, together with better measuring devices to detect these displacements, cannot be over emphasized.

If the necessary technological innovations were combined with socio-economic considerations, the number of dam failures and their tragic consequences could be vastly reduced.

Chitauni dam

The Chitauni dam, an embankment in Uttar Pradesh, India, failed in 1968 with catastrophic consequences to the downstream residents as well as to the state engineers responsible for its design, construction and maintenance. Even before a formal board of enquiry could be constituted, the Chief Minister of the State personally inspected the failure and suspended several engineers connected with it.

It was probably a unique occasion where the hypothesis "that whatever the cause of failure the dam-builders' implication is unquestionable", was exploited to the fullest extent by public officials. This action doubtless indicated the immediate post-disaster public attitude toward the engineers responsible for the supervision of the dams.

It can be argued that the blame for such adverse attitudes can be laid squarely on the engineers, who have until now made little effort to respond to public attitudes and perceptions. However, an irrational and exemplary punishment as was meted out to some of the state engineers during the Chitauni failure, seriously handicapped the activities of many senior and junior state engineers during subsequent floods.

A large number of engineers responsible for the supervision of dams later stated that during the subsequent floods, a sense of insecurity and nervousness prevailed because of the Chitauni episode. The psychological effect partially paralysed their effectiveness in emergency decision-making, thus thwarting future emergency operation.

Deliberate destruction of dams

Deliberate measures have often been taken to destroy dams in the past, including bombing and strafing during wars, sabotage, and voluntary demolition for public safety.

The Eder and Mohne dams in Germany, both gravity structures more than 100ft high, were breached as a result of bombing by the British air force[33] during the Second World War. The resulting floods inflicted a heavy loss of life (about 1200) and considerable property damage.

Two Spanish dams, Burguillo (297ft) in Avila, and Ordunte (182ft) in Burgos, were partially destroyed in 1937 during the Spanish Civil War.

It seems logical that higher dams, with greater disaster potential, have often been the target of hostile action. With the rapid increase in the number of large dams throughout the world, the potential risks of such disasters have increased considerably.

The 267ft-high Hwachon concrete gravity dam, built across the North Han River, was a target for destruction during the Korean War. The dam, constructed by the Japanese during the Second World War, was considerably damaged and substantial repairs had to be carried out[34]. Other examples of sabotage and wilful destruction include the following cases.

A dam on Oak Orchard Creek at Shelby, New York, was publicly blown up by farmers on May 29, 1894. It was claimed that the dam had been responsible for a flood which inundated crops[35].

In 1898, the 22ft-high Tampa masonry gravity weir, having a crest length of 600ft, was dynamited by persons opposed to its construction[36]. The dam belonged to a Florida power company.

In 1964 the Mombasa earthfill dam in Kenya was destroyed during the revolt by the Digo tribe.

In 1966, an earthfill dyke impounding a sediment basin for a lead and zinc plant near the Bulgarian town of Vratsa was breached, sending a 15ft wave of water through the towns of Zgorigrad and Vratsa, which destroyed 196 houses and killed 600 people. It was suggested that sabotage was probably the cause of the disaster[37].

Fortunately, cases of sabotage are not frequent in the statistics of dam disasters, although the reasons for this are difficult to determine, especially when viewed in the light of recent airplane hijackings and bombings in many countries. Damage potentials of dams are considerable, and hence they should be closely guarded from possible hostile action.

Similarly, enemy action against dams has also been rather limited. The bombing of the Eder, Mohne and Sorpe dams was well publicised, as was the torpedoing and blasting of the Hwachon concrete gravity dam in the Korean War. In spite of these well-known events, sabotage of dams and reservoirs has been comparatively rare, and little attention has therefore been paid to this aspect by designers and planners.

Nevertheless, the possibility of sabotage cannot be ruled out in the future. With the increased disaster potential of existing large dams and consequent adverse effects of possible disasters on the socio-economic structure of society, such sabotage may become more frequent in the future. The choice of dam sites and their design should take due consideration of such strategic factors affecting the overall safety.

Man's wisdom has generally followed (but seldom preceded) the undesirable consequences of his actions, and possible sabotage of dams should be taken into account in future.

Very few dams have been voluntarily destroyed or removed in the past following recognition of the potential danger they posed to the community. Several old dams that had already outlived their usefulness have failed in the past with serious consequences. However, with more vigilant and effective schemes of supervision, retirement and modification of existing dams, it should be possible to reduce the number of disasters substantially.

In the case of the Matilija dam in California, the progressive deterioration of the concrete and the foundation made it difficult to operate at full reservoir level, and the owners were asked to lower the level and replace the dam[37]. The decisions taken were greatly influenced by the lessons learnt from the Baldwin Hills dam failure, and by the pressure exerted by the company that had insured the structure against failure damage.

The Drum After Bay dam, which had deteriorated due to concrete disintegration and was considered unsafe, was replaced by a new dam downstream, and the old dam was destroyed by blasting[38]. The measures were taken in time and they improved the safety standards of the existing structures.

The failure to destroy such unsafe structures in time may create serious economic and social problems.

The Hales Bar dam, one of the Tennessee Valley Authority's eight acquired dams, was wisely retired due to excessive and persistent foundation leakage[39]. It should be noted that the care of old dams, ie. abandonment, strengthening, or enhancing the spillway capacity, etc, is a basic policy of the TVA.

A better criterion for decision-making with regard to dam safety, based on considerations of socio-economic benefits and costs, is thus gradually replacing highly-arbitrary human judgement. It is a significant improvement on the earlier approach.

Dominy has discussed[40] the programmes of the US Bureau of Reclamation for continued vigilance over dams and reservoirs. The Bureau's experiences show that in most old dams, the concrete, foundation and spillway deteriorate due to continued operation. Often the structures might superficially appear to be safe, but may in fact, be dangerous. All timely corrective measures are bound to be beneficial and economic in the long run.

Other authors such as Cortright[41], Jansen[42] and Taylor[43] have also emphasized the necessity and value of perpetual vigilance over dams.

Human judgement has played an important role in estimating the safety of structures. The examples already cited clearly indicate that there is a great need to exercise such judgement with the utmost caution, and it is a major human dimension in dam safety.

Eberhardt has also stressed this aspect[25] and has shown that there are as yet too many uncertainties involved in decision-making based on judgement factors. It is, therefore, necessary to devise techniques to reduce the range of uncertainties as much as possible.

Philosophy of dam safety

Man-made reservoirs are of considerable socio-economic benefit to society. Some of the benefits are water supply, irrigation, hydro power, navigation, low-flow augmentation and recreation. At the present state-of-the-art, dams are liable to failure. While some dams have failed in the past with adequate advance warning and little damage, many have failed suddenly and unexpectedly resulting in substantial losses.

With the increasing losses due to dam disasters, designers and researchers have started asking basic questions on the philosophy of dam and reservoir failures.

One school of thought, supported by Biswas[1,2,44], Eberhardt[25] and Gruner[45], contends that:

> "Every dam which impounds water presents a potential danger which should neither be under nor over-estimated. The risk of sudden disaster is forever inescapable, and while knowledge and vigilance may reduce such a risk, it can never be entirely banished. All man-made works carry within them the seeds of their own decay and eventual destruction."

An editorial in the journal WATER POWER stated[46]:

> "Every dam which impounds water presents a potential danger and the risk of disaster can never be entirely banished. This would be a dangerous statement to trust to the tender mercies of the popular daily press, but it is at the heart of the thinking of the born engineer."

It is rather sad that such concern has to be expressed when informing people of a realistic scientific fact. If the public can be properly informed, their realization and acceptance of this fact may mean the establishment of better guidelines on dam safety. The engineer's job is not only to construct dams but also to devise means of better public information and perception of the basic engineering problems and risks involved.

It could develop favourable public response to the improvements necessary to solve these complex problems, even though immediate solutions may not be available. The truth is that the past engineering-economic analyses did not directly include the welfare of the people; they only attempted to maximize economic efficiency.

Today, the concern for safety is an important factor in the design, construction and maintenance of dams and reservoirs[9], but much remains to be done in reducing the risks imposed on the community by such man-made structures.

It is suggested that in the long run it may be more harmful to the profession and to the further development of dam technology to keep the simple probabilities about the risks posed by dams a secret from the public.

Proper public perception of these problems may entail the following:

(1) Better understanding and realization by the public of the engineers' role in dam design. An apparently safe dam may fail later because it is impossible and impracticable to design it for all possible conditions.

(2) Support for intensive research efforts in dam safety.

(3) Better and more timely management decisions which have hitherto been made only after the occurrence of disaster. As Shirley-Smith comments: "It is good to know that since the recent floods, the government announced that it would support the Institution's project for further investigation of flooding in Great Britain."[4]

(4) Better communication with the public so that accurate information on the dams and the risks associated with them can be provided.

(5) More funds for proper disaster planning for efficient management of normal and post-disaster operations.

The disclosure of the possibility of dam failures to the public may thus enhance the profession of dam building. Currently, efforts are being made to assess the implications of calculated risks of failures of dams, and the necessary counter-measures required to minimize the hazardous consequences.

The existence of calculated risks of failures in the hydrologic design criteria of dams has been demonstrated by Biswas[1,2,44] and Yen[46] by using stochastic probability theories. This risk is the result of uncertainty in the natural hydrologic cycle, and is impossible to eliminate unless weather can be completely regulated and controlled by man.

Assuming that this is possible, which is debatable, there are several other design and structural uncertainties which can also contribute to failure. At the present state-of-the-art it is difficult to visualize how these various risk factors can be controlled to such an extent that the failure probability can be reduced to zero.

Obviously it will have to be accepted that the risk of failure cannot be completely eliminated.

Huggenberger, however, has put forward a completely contradictory view. He suggests[15]:

> "Based on 45 years of experience in the design and development of mechanical and electrical measuring instruments, of remote control installations with indicators and recorders, of consulting for placing instruments in more than 130 dams and on the widespread experiences in the field, I am convinced that (dam) failures and catastrophies can be avoided."

This conclusion seems to have been based on the theory of "cause and effect". He suggests that a comprehensive assessment of the actual safety of dams can be based on suitable methods of computation, model tests, and constant surveillance, including observation of concrete, foundations, abutments, basin slopes, seepage water analysis, etc, and scientific analyses based on investigations of creep, stress-strain conditions, autogenous growth, plastic behaviour and other fundamental observations.

These factors can be appropriately organized and critically evaluated to interpret the security of structures, and then suitable criteria could be developed to avoid any failure. He suggested that dam failures can completely be eliminated when the theory and practice of design, construction and supervision attains the necessary perfection.

Serafim and Guerreiro have also suggested[47] that such a state of perfection can be attained.

(To be continued)

all the test stands and the selection of a suitable value can only be the result of compromise. (This is also true for the Francis test stands, values for which are not shown.)

Whatever values are selected will be outside the stated range of at least a few stands, but the difficulties of achieving the required value will depend on the exact interpretations of the questions made by the laboratories and the degree of conservatism with which they have been answered.

In suggesting a possible standard value of $D\sqrt{H}$ it is probably more acceptable to a laboratory to increase its normal value of $D\sqrt{H}$ than to decrease it, either by testing smaller models or testing at lower heads or a combination of the two.

This implies that a value of $D\sqrt{H}$ should be chosen above the mean of the possible range.

Based on this rather subjective view, acceptable values for standard testing of models might be: $D\sqrt{H}=1{\cdot}0$, for Kaplan turbines; and $D\sqrt{H}=1{\cdot}3$, for Francis turbines.

The acceptance of these, or similar, values of the pseudo Reynolds' number would depend not on a statistical treatment of the data at present available but on the practical consideration of such factors as circuit losses, pump power, and hydraulic stability appertaining to each test stand.

A generally acceptable value could only be established after reference to each test stand operator.

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References

1. IEC International code for model acceptance tests of hydraulic turbines. IEC Pub. 193, 1st edn. Geneva: International Electrotechnical Commission, 1965.
2. Cited in Muehlemann, E. "Zur Aufwertung des Wirkungsgrades von Ueberdruckwasserturbinen", *Schweiz. Bauztg*, 1948, 66(24), pp 331-333.
3. Moody, L. F. "Efficiency and power step-up", *Proceedings ASCE*, 1939, 65, p.1584.
4. Hutton, S. P. "Component losses in Kaplan turbines and the prediction of efficiency from model test", *Proceedings IMechE*, London, 1954, 168(28), pp743-762.

The human dimensions of dam safety PART TWO

By Samar Chaterjee* and Asit K. Biswas*

In this concluding article on the human aspects of dam safety, the authors assume that some failures are inevitable and describe four methods of minimizing the resulting damage

It has generally been recognized that the precise predictions of the behaviour of hydraulic structures, particularly dams, have not so far been possible. It is also difficult to predict as to whether such a state can ever be attained. Yet, Huggenberger and Serafim and Guerreiro do emphasize the possibility of eliminating failures and disasters in the near future.

It is difficult to agree with such statements.

The two schools of thought are rather divergent. While Biswas and Grüner have conceptualized an existing real-world situation based on historical observations, Huggenberger suggests a normative model serving as a motivation to improve the theory and practice of dam safety up to perfection.

Admittedly, it should be possible to reduce the uncertainties currently associated with the design and operation of dams and reservoirs to a considerable extent, but, because of several extremely difficult constraints, it is difficult to foresee how dam failures can be completely eliminated.

It is therefore suggested that it would be profitable to use some form of systems' approach to develop rational safety criteria for dams, so that current practices of design, construction and maintenance can then be tested on the basis of the criteria developed. With further development of knowledge through research and supervision of existing new structures, the criteria can gradually be improved.

Since it is suggested that it is impossible to eliminate dam disasters completely, and all that can be done at present is to reduce the probability of such events, four

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Table III—Dam disaster prevention

Corrective measures	*Preventative measures*
(a) Dam safety supervision of: (i) Planning, (ii) Design, (iii) Construction, (iv) First filling, (v) Operation.	(a) Disaster plain regulation: (i) Zoning ordinances (ii) Subdivision regulations (iii) Building codes (iv) Others
(b) Flood forecasting	(b) Warning signs
(c) Watershed treatment	(c) Public education and mass media systems
(d) Urban redevelopment (including permanent evacuation, flood proofing, etc.)	(d) Insurance
(e) Others	(e) Taxation
	(f) Others

alternatives can be effectively used to alleviate damages. They are zoning, insurance, warning system and legislation.

Zoning

The term zoning has until now generally been applied to flood-plains management. However, in the context of dam disasters, it may have a different emphasis and significance.

Table III shows a comprehensive approach to dam disaster prevention in the light of Jensen's suggestion[48]. It shows that dams and reservoirs are one of the primary methods to prevent flood damage, but it should be noted that the dams and reservoirs are themselves subject to failures which can cause disasters of immense magnitude resulting in considerable human suffering.

Thus, it is suggested that the preventative measures undertaken should include due consideration of the possible failure of hydraulic structures. As Hinderlinder suggests[49]:

> "Every dam, regardless of its size, is in some degree a potential menace . . . great conflagrations are subject to control by modern methods, and science has developed means for successfully combating the ravages of diseases and epidemics; but no means will ever be contrived for overcoming the ruthless destructiveness of huge bodies of water suddenly released from restraint."

The best approach to overcoming severe damage due to sudden releases of vast quantities of water is to prevent their occurrence. As discussed earlier, it can be done to a great extent by effective supervision and control of dams and embankments. The other way would be to attempt to reduce the losses by not developing the hazardous area[50].

The area that will be flooded by a breach or failure of a dam can be determined fairly accurately by model studies, and detailed flood maps can be prepared. The maximum height and velocity of water at any point on different time horizons can also be predicted easily.

De Marchi carried out a study[51] on the effects of a flood resulting from the breaching of the Cancano I dam in the Italian Alps. He developed a technique for determining the area of flooding by model tests and analytical computations based on the differential equations of Saint Venant.

The method can be used to predict the maximum height of water at any point and the time required for the flood to reach any location on the floodway, and also to develop maps of flooded areas following dam failures.

In a study of the Sihl reservoir, near Einsiedeln, Switzerland, such analyses revealed that the water released by a breach in the concrete dam or the earth dyke could be retained by building a subsidiary dam farther down the valley, thus avoiding inundating a part of Zurich and its railway marshalling yard. The cost of this protective measure, though quite substantial, compared favourably with the anticipated disaster losses[45].

A study of various dam breaches indicates that the flooded area can be divided into three typical zones, depending on the risk of probable damage. A brief description of these zones and their characteristics follows:

Prohibitive zone. This is the immediate zone downstream where people and property have practically no chance of survival. This is the so-called "ground zero" or the zone of impact, and the direct path of the flood waves is included in this zone. Habitation in these areas should be completely prohibited, and no permanent structure or public services should be allowed.

The area may be used for agricultural purposes, possibly with underground structures below the scour depth level so that loss of life and damage to property can be reduced to an absolute minimum in the event of failure. The agricultural products would be a total loss if and when a failure occurs.

Restrictive zone. In this zone, the destructive effects of the flood are not as severe as in the prohibitive zone, yet the impact is quite substantial, and land use would have to be regulated from the standpoint of permanent structures and normal human and economic activities.

Unless it were possible to provide special subsidiary protective structures against possible disasters, normal human activities should be severely restricted in this area. However, it might be possible to allow some activities that may have to be specially planned for this type of area.

Warning zone. The severity of losses in this area is moderate, and the necessary warning and evacuation facilities would be available. Thus, in the event of a dam breach it should be possible to save lives and properties partially or fully. Special land-use planning, including structural and non-structural measures and suitable warning and evacuation systems, would be a prerequisite for such areas.

Further study of dam disasters that have occurred in the past, and those that are likely to occur in the future, would probably provide a more elaborate classification of zones and more useful data on effective social regulations in the downstream regions of large dams.

A considerable number of studies has been carried out on flood-plain zoning, but it is rather surprising to note that this technique has generally been ignored in the past by the planners for dam breach problems.

Disaster warning system

In certain dam disaster cases, it may be possible to forecast the event some time before it happens so that people can be evacuated from the threatened area. In the Baldwin Hills disaster, the time available between first detection of the failure symptom and the final impact was used quite effectively, and many lives were saved.

Some failures, however, cannot be foreseen. The Vajont disaster may be considered one of this type, even though opinion is divided as to whether the failure symptoms could have been interpreted as a warning of the approaching catastrophe. One of the major lessons to be learnt from Vajont is that creeping movements, as observed at Mount Toc, should be considered dangerous.

In a recent study[52], it was pointed out that "Some generalization of stage, damage, and time of warning relationship seems possible both structurally and geographically" in the flood plains. While this may be possible in the case of floods, it should be realized that man's reactions to flood warning are varied, and hence the relationship between the benefits of warning and the warning action is difficult to predict. It is, of course, quite evident that a warning system is a major factor in reducing damage.

There are some fundamental differences between the warnings issued for dam disasters and for usual floods. People are reasonably familiar with floods because of their frequent occurrence, but as dam failures in any particular region are few and far between, people find it difficult to even conceive that dams, which look as solid as the Rock of Gibraltar, can fail.

Other aspects of dam breaches are their suddenness, short duration and vehemence; hardly any other flood is as sudden. The warning and evacuation system devised should be able to accommodate these particular characteristics.

From past experience, it has been observed that about 8 to 12 hours of flood warning was quite adequate for almost complete response in small communities[52]. The beneficial effects of warning in flood damage reduction is thus quite obvious. Also, the time of the warning has an important bearing on its effectiveness and benefits. It seems that night and weekend warnings have lesser impact than midweek daytime warnings.

Such observations should be carefully considered when designing suitable warning systems, and in general, effective use of past experience and an adequate knowledge of human behaviour during emergencies are both necessary for efficient planning.

Kiersch has pointed out[53] that a few days before the Vajont catastrophe some animals showed signs of unrest. Stini, in 1930, had recommended[54] that "the ability of certain animals to detect slides in advance" may be successfully used "by keeping them in the respective areas and observing them."

It does seem that effective warning may often be obtained by carefully observing and studying the perceptions and attitudes of animals in the area, and it is interesting to note that man, with all his sophisticated scientific knowledge and instrumentation, cannot predict the occurrence of some natural events as accurately as certain animals.

It has been suggested[37] that an adequate warning system should be automatic in all reservoirs, but because a dam may fail in different ways it is difficult to improvise an alarm system which is fully automatic, comprehensive and reliable.

An unreliable alarm system may prove to be more dangerous and catastrophic in the long run.

Computers are now being used increasingly to process hydro-meteorological data from the catchment as well as the measurements from instruments located in the dam, foundation and the surrounding area to record stress, strain, temperature, displacement, inclination, level, seepage and other pertinent parameters. The processed data can then be analysed accurately and quickly for better decision-making.

Instruments for automatically recording parameters and transmitting collected data to a centralized processing unit have already been developed to a reliable degree of sophistication. Prompt measurement and processing of data, and subsequent analyses and interpretation, will improve decision-making, which in turn will improve the safety performance of dams and reservoirs by allowing reliable and timely warnings to be issued. As yet, however, such devices have been installed only in a few select dams.

The accuracy, reliability and efficiency of these instruments can gradually be improved by taking advantage of current research efforts and evaluation of their present and past performances.

When a dam, because of its location, might become a danger to more than one country, state or province, the task of warning may be further complicated, and it needs special study in view of the public's increasing safety consciousness. The development of international and interprovincial co-operation in the field of dam safety research is thus a step in the right direction, while feasible comprehensive answers to the problem can only come from joint efforts.

Warning systems should be properly maintained at all times, and efficient warning devices should be installed in dams because communication lines can be disrupted in many different ways. It may be necessary to test the warning systems at least once a year, and the community living with the risk should be made fully aware.

It is essential to develop this awareness of the existence of a potential risk, and also to remind people regularly of the action to be taken promptly in response to the alarm.

Admittedly, the publicity of an effective alarm system may prove to be quite disturbing to the local inhabitants. The area may no longer be considered a safe place to live, and a large number of inhabitants may decide to move to a safer area. It could also possibly retard the economic development of the threatened area.

As mentioned before, this situation is preferable to one of ignorance and dangerous bliss.

Dam safety insurance

Saventhem and Muller[8] define insurance as a device to protect the individual (and thus indirectly the community) against the financial consequences of fortuitous events causing personal injury or property damage. The dam insurance scheme, if it is ever put into practice, will protect the community against any possible financial damage due to dam disasters.

Table 1 shows the estimated cost of damage resulting from some selected dam failures. It is quite possible that part of the total cost of the damage involved will be beyond the financial capacity of the owners of the dam. Even in developed countries, the total cost of some disasters could seriously affect the national economy.

The effect of the Malpasset dam failure on the French economy is well known, and the consequences were further aggravated by the reluctance of France to accept foreign aid because of national pride.

Considerable research is now under way to improve and develop new techniques for dam safety. New methodologies, including preventive and protective measures, are being used successfully within the framework of existing public programmes to minimize losses due to dam disasters. The techniques, however, have often failed to provide the necessary measure of safety demanded by the people.

The adverse reaction to the failure of the Baldwin Hills, Malpasset, Vajont and Khadakwasla dams is an indication that modern dam-building technology has failed to make the adjustments necessary with the society's growing demands for safety. A definite provision for financial aid is therefore necessary to compensate for losses which may arise due to dam failures.

It is generally accepted that the programme of dam safety insurance can complement and encourage preventive and protective measures[55]. When the Matilija arch dam in California, insured to cover a risk of $5 million, showed serious deterioration in the concrete, the insurers asked the owner (a municipal authority) to lower the water level without delay.

The water level was immediately lowered by 9m, and later the replacement of the dam was demanded to ensure safety[15].

Thus, it is quite obvious that an effective insurance policy would lay a strong emphasis on continued improvement of supervision of dams by their owners, and reduce the risk of failure. The onus will be on the owners to comply with the recommendations of the insurer's experts on design, construction, operation and maintenance.

Feasibility of insurance

Initiation of an insurance programme for dams can be strongly justified[8] on the basis of a principle of "common need".

> "Every reservoir that stores water causes danger which should neither be underestimated nor overvalued. The risk of sudden failure and escape of water cannot be banned . . . this tragic knowledge may remind men that social and legal protection must be granted to people living under flood risk."[37]

However, development of an effective insurance programme will be dependent on the capacity of the world insurance market; on the development of criteria for suitable comprehensive coverage on a common need basis; and on the solution of financial, technical and administrative problems associated with the establishment of such an international scheme.

If adopted, such a scheme might provide a comprehensive insurance programme that will spread the losses due to dam disaster over the whole community of dam owners.

During the last 20 years, the total estimated damages have been conservatively estimated around $1000 million for 50-odd failures. Since there are about 10 000 large dams, the cost of premiums per dam per year need not be prohibitive, and obviously the premium will have to be geared closely to the hazard potential of a dam.

In fact, it could be shown that no risk was so great that it could not be covered at rates the owners could afford. Grüner, for example, has suggested[37] compulsory insurance of $10 million.

The US National Flood Insurance Act of 1967 provides[56] a flood insurance programme "on reasonable terms and conditions" with "large-scale participation of the Federal Government carried to the maximum extent practicable by the private insurance industry". The term "flood" includes all inundation from the overflow of streams, rivers, or other bodies of natural water, and from tidal surges, etc.

In Norway, insurance can be bought for dams to cover against damage by natural external factors (flood, avalanche, etc), but the cover does not include failures due to defects in the foundation or materials[57]. It may be noted that insurance cover for third-party risk due to dam failures, though generally not very popular, is already available in varied forms in a few countries.

There is some form of supervision for dams in every country, yet dams fail because either the standards of supervision are not adequate or the knowledge was not available to prevent the failures.

Takase[58] and Londe[59] have shown that different countries treat identical problems in different ways, and such a variation in supervision standards exists that a failure which may be considered an act of God in one country could be considered the result of serious errors in another. The problem is further complicated by the opinions of experts which may be seriously divided, as in the cases of the Vajont and Malpasset disasters.

Even though dam safety insurance may be economically feasible at this stage, it has not been possible so far to devise an internationally-acceptable type of insurance for dams.

Legislation

In 1929, after the failure of the Saint Francis dam, safety laws were passed by California State, which brought a great many dams under a system of effective state supervision. Prior to 1929, only a few dams were under limited supervision by the state engineer or the Railroad Commission.

At present, the California Department of Water Resources exercises jurisdiction and control over construction, operation, alteration, repair and behavioural surveillance of all dams in the State, except those under the minimum legal size or those owned by the Federal Government[60].

Several states in the USA and several countries have since enacted similar legislation. However, aspects other than supervision, ie. disaster planning, compensation for loss, and penalties, have not yet been included in legislation.

The US National Committee of ICOLD has recently suggested[61] a uniform set of state laws for dam safety. It offers a greater emphasis on the stability of foundations, reservoir banks and environment, and also stresses safety against seismic effects. If uniformly enacted, it would be a step in the right direction.

In the UK, following the occurrence of the Dolgarrog disaster and the Skelmorlie failure, the Reservoir (Safety Provisions) Act was passed in 1930. The Act was revised in 1966, but has yet to be approved by the Government.

In 1966, a group of international experts under the aegis of UNESCO, prepared a comprehensive document[62] on what was needed to reduce the consequences of reservoir failures. The primary aim was to minimize the probability of dam failure and thus reduce damage to lives and property.

The study has reviewed the existing national regulations of ten major countries, and could be very useful to those countries which do not as yet have any satisfactory laws.

As far as the authors are aware, most of the provinces in Canada lack similar laws, and it is high time serious consideration was given to the matter.

Conclusions

Generally, the problem of dam safety has long been considered to be a technical subject, and the significance of the human aspect in the overall problem of dam disasters has seldom been recognized.

The reasons for this past neglect are many: lack of knowledge regarding quantification of associated benefits and costs; reluctance and indifference at the various levels of government; lack of proper investigation and assessment of past dam failures; dearth of research to test, improve and innovate methods of handling disaster problems; and lack of community perception of the problems.

Obviously, much research has to be conducted to resolve some of these complex affairs. Studies of the Vajont, Baldwin Hills and Chitauni dams indicate the great potential of investigation and regulation of human aspects of dam safety, along with the resulting benefits from such studies.

It is suggested that since the failure of dams cannot be eliminated completely at the present state-of-the-art, our major objective should be to minimize the potential failure losses. This can be achieved by measures such as zoning, disaster warning systems, dam safety insurance and legislative action.

An attempt has been made to put these into their proper perspective and demonstrate their potential usefulness. It should be noted that not much, if any, work has been done to use such measures in different combinations for overall optimum safety.

The question of dam safety is of considerable importance to society as a whole, and the engineers responsible for the design of dams and associated structures should work closely with economists and behavioural scientists to alleviate the problem.

References

1. Biswas, Asit K. "Risk Criteria and Flood Estimation," Hydrology Note No. 1, Queen's University, Kingston, Canada, 1967.
2. Biswas, Asit K. "The Philosophy of Estimating Spillway Design Flood," *Engineering Journal*, Vol 52, No. 1, January, 1969, pp20-30.
3. Markwart, A. H. "Recommendations for Legislations and Application of Law," *Proceedings, ASCE*, Vol 58, No. 1, January, 1932, pp20-27.
4. Shirley-Smith, H. "Disaster in Bridges and Dams," *British Journal for the Advancement of Science*, Vol 125, No. 126, June, 1969, pp386-390.
5. Hogg, T. C. "Social and Cultural Impacts of Water Development," Seminar, Water Resources Research Institute, Oregon State University, Oregon, Spring, 1968, pp11-23.
6. "Earth Dam Washes Out in Brazil," *Engineering News-Record*, April 7, 1960, p25.
7. Garb, S., and Eng E., R.N. "Disaster Handbook," Springer Publishing Co, New York, 1964, pp117-119, 152-157.
8. Saventhem, E. M. D., and Muller, C. A. "Comprehensive Insurance for Dams, Its Scope and Feasibility," *Proceedings*,

Tenth ICOLD Congress, R21, Q38, Vol 3, Montreal, 1970, pp349-363.

9. DICKERSON, L. H. "Supervision of Dams and Reservoirs in Operation," *Proceedings, Tenth ICOLD Congress*, General Report, Q38, Vol 5, Montreal, 1970, pp223-279.

10. QUARANTELLI, E. L., and DYNES, R. R. "Stereotyped Behaviour," *American Behavioural Scientist*, Vol 13, No. 3, Jan/Feb 1970, p325.

11. YUTZY, D. "Priorities in Community Response," *American Behavioural Scientist*, Vol 13, No. 3, Jan/Feb 1970, pp344-353.

12. WARREN, R. "The Community in America," Rand McNally, Chicago, USA.

13. DYNES, R. R. "Organized Behaviour in Disaster—Analysis and Conceptualization," Disaster Research Centre, Ohio State University, Columbus, Ohio, 1969.

14. QUARANTELLI, E. L. Personal communication, 1970.

15. HUGGENBERGER, A. V. "Safety and Behaviour of Concrete Dams," *Proceedings, Tenth ICOLD Congress*, Q38, R11, Vol 3, Montreal, 1970, pp169-178.

16. TAKASE, K. "Statistic Study on Failure, Damage and Deterioration of Earth Dams in Japan," *Ninth ICOLD Congress*, Q34, R1, Vol 3, Istanbul, 1967, pp1-19.

17. "Court Convicts Dam Designers," *Engineering News-Record*, March 17, 1960, p26.

18. "The Malpasset Verdict," WATER POWER, Vol 17, No. 1, January, 1965, p32.

19. SHERARD, J. L., WOODWARD, R. J., GIZIENSKI, S. F., and CLEVENGER, W. A. "Earth and Earth-Rock Dams," John Wiley & Sons Inc, New York, NY, 1963, pp113-199.

20. CIRIACY-WANTRUP, S. V. "The Role of Benefit Cost Analysis in Public Resource Development," 1955, p12, quoted by HOGG, T. C., op cit.

21. QUARANTELLI, E. L., and HAAS, J. E. "The Vajont Dam Disaster," *Working Paper No.* 1, Disaster Research Centre, Ohio State University, Columbus, Ohio, 1963, p38.

22. IBSEN, C. A., and BALLWEG, J. A. "Public Perception of Water Resource Problems," *Report*, Water Resources Research Centre, Virginia Polytechnic Institute, Blacksburg, September, 1969, p102.

23. FELD, J. "Lessons from Failures of Concrete Structures," *Monograph No.* 1, American Concrete Institute, Detroit, Mich, 1964.

24. RAYNER, J. F. "Studies of Disasters and Other Extreme Situations—An Annotated Selected Bibliography," *Human Organization*, Vol 16, No. 2, Summer, 1957, pp30-40.

25. EBERHARDT, A. "Judgement Factors in Inspection of Dams," WATER POWER, Vol 21, No. 11, November, 1969, pp431-435.

26. DYNES, R. R. "Community Reaction to Water Resource Problems in Relation to Planning," *Proceedings, Workshop on Sociological Aspects of Water Resources Research*, Utah State University, Logan, Utah, April 18-19, 1968, pp16-20.

27. ANDERSON, W. "The Baldwin Hills, California Dam Disaster," *Research Note No.* 5, Disaster Research Centre, Ohio State University, Columbus, Ohio, 1964, p49.

28. "Medal for Many," *Engineering News-Record*, Jan 16, 1964, p68.

29. "Oil Firms Sued," *Engineering News-Record*, Dec 24, 1964, p43.

30. "Dam Failure Lawsuit Settled Out of Court Room," *Engineering News-Record*, Mar 19, 1970, p59.

31. GRANT, U. S., and SHEPPERD, W. E. "Some Recent Changes in Elevation in the Los Angeles Region of Southern California and their Probable Significance," *Bulletin, Seismological Society of America*, Vol 29, No. 2, 1939.

32. "Investigation of Failure of Baldwin Hills Reservoir," California Department of Water Resources, Sacramento, April, 1964.

33. KOENIG, H. W. "Damage to the Sorpe Dam by Vibrations and Repair Work," *Ninth ICOLD Congress*, R29, Q35, Vol IV, Istanbul, 1967, pp485-497.

34. "War-Torn Dam Gets Big Repair Job," *Engineering News-Record*, April 2, 1959, pp38-40.

35. *Engineering News*, June 14, 1894, p485.

36. *Engineering Record*, Volume 29, p94.

37. GRUNER, E. "The Safety of Reservoirs," *World Dams Today*, Japan Dam Association, Tokyo, 1967, pp104-109.

38. PIRTZ, D., et al. "Investigation of Deteriorated Concrete Arch Dams," *Journal of the Power Division, ASCE*, Vol 96, No. PO1 January, 1970, pp23-38.

39. LUDIN, L. W. "Inspection and Maintenance of T.V.A. Dams," *Proceedings, Tenth ICOLD Congress*, Q38, R25, Montreal, 1970, pp427-442.

40. DOMINY, F. E. "Safety of Dams—A Reclamation Action Program," *World Dams Today*, Japan Dam Association, Tokyo, Japan, November, 1967, pp238-241.

41. CORTRIGHT, C. J. "Re-evaluation and Reconstruction of California Dams," *Journal of the Power Division, ASCE*, Vol 96, No. PO1, January, 1970, pp55-72.

42. JANSEN, R. B. "Evaluation of Dam Safety in California," *Journal of the Soil Mechanics and Foundations Division, ASCE*, Vol 93, No. SM3, May, 1967, pp23-36.

43. TAYLOR, K. V. "Some Unusual Aspects of Dam Safety Studies in Western United States," *Proceedings, Tenth ICOLD Congress*, Q38, R28, Vol 3, Montreal, 1970, pp465-488.

44. BISWAS, A. K. "Spillway Design Flood," WATER POWER, Vol 20, No. 4, April, 1968, p137.

45. GRUNER, E. "Dam Disasters," *Proceedings, ICE*, Vol. 24, London, January, 1963, pp47-60.

46. YEN, B. C. "Risks in Hydrologic Design of Engineering Projects," *Journal of the Hydraulics Division, ASCE*, Vol 96, No. HY4, April, 1970, pp959-66.

47. SERAFIM, J. L., and GUERREIRO, M. "Some Rules Used for the Observation of Concrete Dams," WATER POWER, Vol 22, No. 5/6, May/June, 1970, pp181-189.

48. JENSEN, J. G. "Geographic Research on Flood Plain Occupance," *Proceedings, Water Resources Research Institute Seminar*, Oregon State University, Corvallis, 1968, pp77-102.

49. HINDERLINDER, M. C. "Necessity for, and Penalties for Lack of Supervision," *Proceedings, ASCE*, Vol 58, No. 1, January, 1932, pp28-41.

50. "Flood Damage Outpaces Flood Control," *Engineering News-Record*, August, 1966, p38.

51. GRUNER, E. C. "Vigilance Over Reservoirs," *Water and Water Engineering*, September, 1969, pp369-373.

52. DAY, H. J., BUGLIARELLO, G., PHP, and HOUGHTON, V. T. "Evaluation of Benefits of a Flood Warning System," *Water Resources Research*, Vol 5, No. 5, October, 1969, pp937-945.

53. KIERSCH, G. A. "Vajont Reservoir Disaster," *Civil Engineering*, Vol 34, No. 3, March, 1964, pp32-39.

54. "Vajont Slide—Seven Years Later," *Civil Engineering*, Vol. 40, No. 6, June, 1970, p86.

55. PARKMAN, C. C. "Supervision and Control of Llysyfran Dam and Reservoir," *Proceedings, Tenth ICOLD Congress*, Q38, R59, Vol 3, Montreal, 1970, pp1143-1160.

56. Committee on Banking and Currency, Nineteenth Congress. "National Flood Insurance Act of 1967," HR 1197 Hearings, US Government Printing Press, Washington, DC, 1967, p253.

57. SUNDT, B. "Supervision of Dams and Reservoirs in Operation," *Proceedings, Tenth ICOLD Congress*, Q38, R46, Vol 3, Montreal, 1970, pp871-880.

58. TAKASE, K. op cit, p9.

59. LONDE, P. "Recent Developments in the Design and Construction of Dams and Reservoirs," *Proceedings, Tenth ICOLD Congress*, Q37, Vol 5, Montreal, 1970, pp143-221.

60. California Department of Water Resources. "Status and Regulations Pertaining to Supervision of Dams and Reservoirs," Sacramento, 1969, p39.

61. "Model Law on Dam Safety," US National Committee, ICOLD, Washington, DC, 1970.

62. "Recommendations Concerning Reservoirs," UNESCO, Paris, November, 1966, p35.