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FACTORS OF INFLUENCE ON THE SELECTION OF SURFACE SPILLWAY CONTROL SYSTEMS IN DEVELOPING COUNTRIES (*)

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1. INTRODUCTION

The safety risks associated with controlled, or gated spillways are well known and understood and there is much documented information describing related incidents and accidents over the years. The risks, requirements and impacts of spillway flood gates are, however, extremely sensitive to the circumstances of the environment in which they are to operate.

Each of the various available spillway control systems offer particular operational advantages, which will be more, or less appropriate and beneficial in the specific circumstances inherent to each dam. If, however, a solid uncontrolled spillway crest is taken as the benchmark, to a greater or lesser extent, each of the advantages that are offered by other systems carry a compromise in terms of complete reliability and/or reliance on mechanical, or human intervention. In this paper the authors seek to highlight the respective "compromise" of various popular spillway control systems within the context of a range of environments and situations typical of a developing country.

(*) *Facteurs influençant le choix du type de vanne sur les évacuateurs de crue dans les pays en voie de développement.*

2. BACKGROUND

As a developing region, southern Africa, with its broad spectrum of contrasting environments, represents a good platform on which to evaluate the operational application of the various available spillway control systems and to illustrate related problems. The major river and catchment transfer systems managed by the Department of Water Affairs and Forestry (DWAF) of South Africa represent a relatively sophisticated and well controlled environment, while in certain areas of Angola or the Democratic Republic of Congo, a dam may currently be completely un-managed and even the target of military sabotage.

When designing spillway control systems for implementation in the environments typical of southern Africa, it is particularly important to take into account all factors of influence, as presently exist and as could possibly develop in the future, or over the "lifespan" of the scheme. For example, urbanisation, drought, disease, or civil war could cause a complete rural area to be de-populated, with the consequent abandoning of a dam. Other factors to consider are changing priorities, organisational capacities and institutional frameworks

In many instances, mechanical gates can offer significant operational and economic advantages. Dam safety can be enhanced through the ability to manage floods and the implementation of discharge control can often reduce overall capital development costs. Whilst economics and dam safety will usually represent the first considerations in relation to implementing gates on a dam, there are other factors that, in certain cases, may be of overriding influence

3. TYPICAL OPERATING ENVIRONMENTS AND SITUATIONS IN DEVELOPING COUNTRIES

3.1. General

Southern Africa is home to a significant diversity of social environments, from the sophisticated infrastructure of urban South Africa, to the nomadic world of the Himba tribes of northern Namibia and Angola, whose lifestyles have changed little over the past centuries. The nature of the actual environment of implementation, particularly from a social point of view, will impact greatly on the appropriateness of each of the various possible operational systems for spillway flood control. In this section, the authors illustrate, by way of example, the diversity of environments and situations in which dams are operated in southern Africa, with particular emphasis on social factors and problem areas

3.2. Water systems managed by large organisations

Large catchment systems and water supply and transfer schemes in South Africa are managed and operated by DWAF or, in a number of instances, water boards. DWAF maintains a strong central management system, as well as regional offices and operational teams at each of their major dams. Extensive experience in the operation, maintenance and management of dams of all sizes and types and with all manner of gated spillways and variations of outlet works is reflected in the very few reported incidents and accidents at DWAF dams over the years. Most DWAF dams with gated spillways include full stop log facilities for gate isolation and this allows frequent inspection, ease of maintenance and safe operational testing.

On the major rivers of South Africa, several of the more significant dams have flood warning systems and various dams benefit from up to two weeks lead time before the arrival of a flood. In such instances the development of flood absorption storage by pre-releasing through a gated spillway can obviously provide significant benefit.

Recently DWAF has implemented simple, user-friendly backup procedures for the operation of flood control gates, as such measures are considered to engender more confident operation during critical flood events.

3.3 Urban environments

Various municipalities around South Africa own and operate their own dams for domestic, commercial and industrial water supply. While most such dams are relatively small and simple, some are not and Witbank dam is an example of a major dam with a high safety risk and intricate and sensitive operation that is managed by the staff of a town engineer.

Witbank dam (see Fig. 1) is a diamond-head concrete buttress structure with a central spillway controlled by 4 No 8.5 m high x 12 m wide radial gates. The dam, which has a full supply storage of 101 million m^3, drains a catchment area of some 3 540 km^2, with a mean annual runnoff of 124 million m^3. Inflow flood warning is qualitative only and sent from a single location, which represents approximately one quarter of the catchment. The rivercourse immediately downstream of the dam passes through a nature reserve and flow releases from the dam directly affect a large number of separate stakeholders, several of whom own property located below the 50 year floodline.

The dam has a total freeboard of only 600 mm and the flood gates can only be actuated from the control facilities immediately above, which are inaccessible if water is discharging over the adjacent non-overspill crests. During a flood, inflow is evaluated by the town engineer with the aid of a pocket calculator on the basis of the rate of storage rise plus any outflow and discharge is adjusted to match inflow through simple measurements/estimations of gate opening. As much of the downstream development is easily affected by flooding, any outflow exceeding inflow can be seen to carry a direct financial impact. To compound this situation, there is likely to be a short warning period of a "severe flood" event, during which time all affected parties downstream must be warned before any gates are opened.

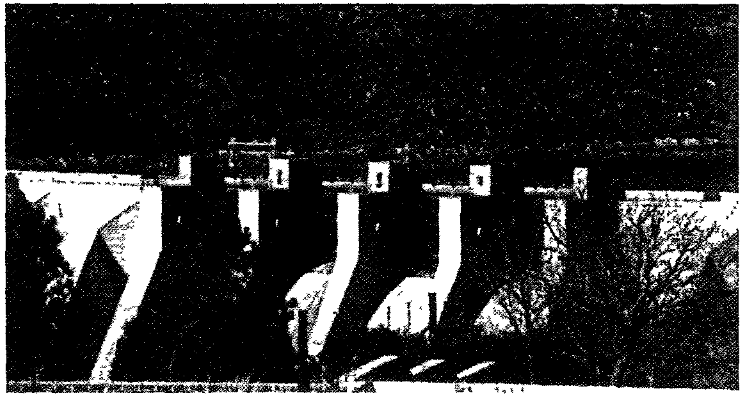

Fig. 1
Witbank dam spillway (South Africa)
Évacuateur de crue du barrage de Witbank (Afrique du Sud)

The tricky and risky nature of the operation of this system can be illustrated by a narrowly averted incident over Christmas 1995 when a flood with an estimated return period of 20 years passed through the dam. The flood event occurred over a period of two days and the main flood peak was preceded by a lesser peak, which was managed with little drama and following which inflow decreased. The second, larger flood peak caught the operators by surprise and the town engineer was called out in the middle of the night to a dam with the water surface depositing debris on the non-overspill crest. With the aid of torch signals, the town engineer and an assistant were able to open the gates sufficiently to stabilise the impounded water level. This 20 year recurrence interval event gave rise to circumstances beyond previous experience, which proved difficult to manage even for a professional engineer.

Another problem in an urban environment is obviously vandalism and sabotage. Windsor dam (see Fig. 2) near Ladysmith, Kwazulu-Natal suffered such an attack recently. The dam, which was commissioned in 1951, has been out of use for a number of years and while there is security, it is not permanently staffed. On 15th July 1998 vandals gained access to the control panel, raising the 12 m wide x 8 m deep main sluice gate by 500 mm. A large quantity of water was released into the Klip River at a time of year when flow is usually at its lowest. Six

children playing in the river at Black Rock, downstream of the dam, were caught unawares by the sudden flow rise and were washed away. Two children were rescued, but four died.

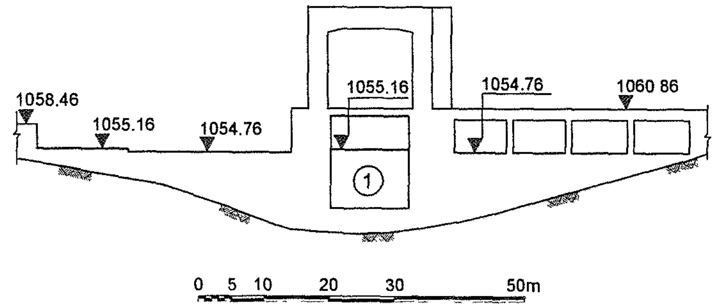

Fig. 2
Illustrative downstream elevation of Windsor dam (South Africa)
Vue schématique aval du barrage de Windsor (Afrique du Sud)

(1) 12 m x 8 m deep sluice gate *(1) Vanne à glissières de 12 m x 8 m de hauteur*

3.4. RURAL SOUTHERN AFRICA

In rural Africa, it is not at all uncommon to see the washing of clothes, or the collection of water, or children playing in a river downstream of a dam (see Fig. 3). In any such circumstances the occurrence of a "sunny day" accidental opening of one or more spillway gates could have major consequences.

With negative population growth rates spreading across southern Africa as a consequence of the increasing influence of HIV and Aids, the loss of key, trained personnel in rural areas where they are difficult to replace is a further reality to consider. Often a single person of the correct abilities and temperament can be the key to the safe and effective operation and maintenance of a spillway gate system. In many instances in southern Africa, the provision of adequately skilled backup personnel is simply not possible.

Many dams in rural southern Africa are situated in relatively remote and inaccessible locations and during a serious flood event, the dam operator may be totally isolated. In the realities of a developing country, it is further significantly possible that a stand-by generator might prove of great value as spare parts for a diesel truck, or that maintenance procedures might not be rigorously followed, or that diesel for stand-by operation might have been stolen.

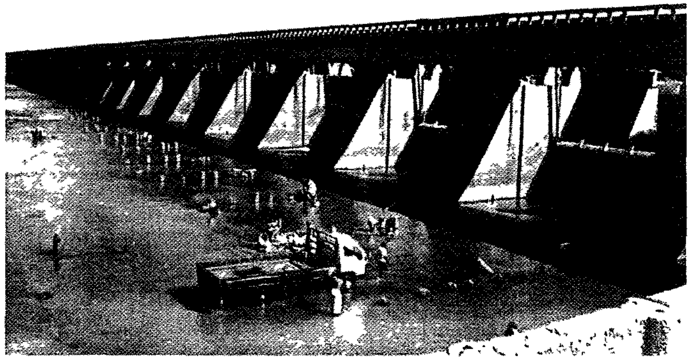

Fig. 3
Washing, etc, downstream of a spillway
Lessive, etc, en aval d'un évacuateur de crue

In a rural environment, a certain level of regional economic dependence on a dam and water supply scheme can develop and issues of dam safety may accordingly take on unusually broad impacts

4. FACTORS TO BE CONSIDERED IN THE SELECTION OF A SPILLWAY CONTROL SYSTEM

4.1. ECONOMICS AND DAM SAFETY

The first aspects to be considered in relation to the selection of a spillway control system for a dam are usually economics and dam safety. Often a gated spillway, submerged or otherwise, can allow significant capital cost savings and gates can facilitate the routing of a flood in such a manner as to maximise overall safety. Gates can allow the selection and control of flow down specific chutes, or the discharge of flow in specific areas, which can be of great advantage The location of gates with sills below full supply level on a dam with a large catchment and good flood warning can further facilitate pre-releases and significant flood absorption. However, the dependence of dam safety on such operation creates a similar dependence on the automatic gate control systems and/or the operational personnel. An uncontrolled spillway should accordingly always be given consideration in any environments in a developing country.

4.2. OPERATING STAFF

The successful operation of flood gates will always be at least partly dependent on the capabilities of the operating staff. While the size of a scheme will often determine the required skill levels of its operators, which may necessitate the importation of personnel from other areas, greater success is likely when the operation is tailored to suit the abilities of the local population. It is, however, very difficult to train dam operational personnel for an exceptional event, which may, or may not occur during their lifetimes. This can become a problem, as mental preparedness and a full understanding are of greatest importance during intense flooding, when the lives of many people can be affected by an inappropriate decision. When considering a spillway control system to be implemented at a dam, it is accordingly important to review the associated operation and maintenance requirements against the locally prevalent skill levels, as currently exist, as well as may be prevalent in the foreseeable future.

For automatically actuated gates, adequate preparedness of the operator in an emergency situation cannot simply be assumed without ongoing training and the support of an effective organisational structure. The conditions that accompany severe flood events tend to include the loss of normal communication channels, access and power supply and the failure of an automated gate actuation system in such circumstances, even in the most sophisticated environment, is a realistic possibility for which contingency plans should be made.

4.3 OPERATION AND MAINTENANCE COMMITMENTS

The problem of ongoing operation and maintenance can be well illustrated through hydropower, which by its very nature comprises sophisticated hydro-mechanical equipment. While the hydrology of southern Africa does not allow the widespread application of hydropower, that of central Africa does. However, installations to date have generally been developed by colonial powers, or former colonists. As major maintenance, refurbishment and upgrading becomes necessary over time, supplementary donor funding is required and an internal ability to maintain plants as economically self-sustaining systems does not always seem to exist. The ongoing devaluation of African currencies can be seen as a particularly critical factor in making sophisticated technology progressively less affordable within this region and the necessary maintenance and refurbishment accordingly become more and more difficult.

As long as it can be certain that those taking responsibility for a scheme will always be in a position to ensure that the requirements of dam safety are met, the application of a gated spillway control can offer real regional benefit through providing employment opportunities and social development. A sensible contingency, however, would be to make provision, at the design stage, for continued safety in the case of eventual abandonment

4.4. CHANGING CIRCUMSTANCES AND PROJECT DEVELOPMENT

Much of the development to date in southern Africa has revolved around the sub-continent's mineral resources. The exploitation of certain of these resources can be seen to be becoming progressively less viable. Long after a mine is consigned to history, its tailings and water supply dams still require management and monitoring. While a particular "lifespan" is considered in the process of economic evaluation of a project, the scheme often continues to provide benefit for a considerably longer period. The actual "lifespan" of a dam is likely to be more sensitive to future local circumstances when dam yield is partly, or completely dependent on the condition of mechanical gates. A cost saving at the implementation of a project can often further result in deferred costs when these can least be afforded.

4.5. ADDITIONAL PROBLEM AREAS WITH INFLUENCE ON SPILLWAY CONTROL SYSTEMS

4.5.1. Alkali aggregate reaction

Several dams in southern Africa are suffering the consequences of alkali aggregate reaction (AAR). In various instances, specific problems have developed in relation to the operation of mechanical equipment. Significant examples are Kariba dam and Owen Falls dam. After symptomatic repairs, the problems at both of these dams are now monitored through management programmes. These cases are, however, high profile schemes that can benefit from foreign donor funding. On a smaller scale and in a rural environment, repair before the problem reaches a critical point is not always a possibility.

4.5.2. The continued understanding of operational impacts

It might be completely appropriate to assume that a water management authority in a developed environment is in a position to understand fully the consequences of each and every operational procedure of a gated spillway in relation to the specifics of the local hydrology. Such an assumption cannot be made in an environment in which circumstances can change significantly over the lifespan of a dam.

Midmar dam in Kwazulu-Natal, South Africa was constructed in the middle 1960s with provision for a future raising using radial gates. The first phase incorporated an uncontrolled spillway crest, with adequate freeboard for the final

gated full supply level. For the second phase, radial gates were to be added above the existing crest sill and the dam was to be operated as a level-pool While developments in hydrological analysis in the interim have significantly changed the design flood hydrology, the original dam and the gated raised dam will display very different flood absorption characteristics. During low recurrence interval flood events, the attenuation developed by the current dam configuration would be completely lost for a mechanically gated dam, applying a level-pool flood routing approach. In practical terms, implementation of level-pool flood routing at Midmar, as originally conceived, would cause the current 1 in 50 year flood development boundary downstream to be overtopped by a flood with a 20 year recurrence interval. Even though it has always been the intention to raise this dam with radial gates, development downstream has since encroached on the river, limited only to the existing 1 in 50 year flood level.

4.5.3. The practicalities of manual override facilities

In remote and inaccessible locations in which complete reliance cannot be placed on mechanical stand-by facilities and communication channels may fail during flood events, manual override for gate operation is essential. In such instances, complete reliance is placed on the operator's competence. However, manual override will only really be of significant benefit if the number of gates is few and the specific site hydrology allows adequate warning time to raise the gates.

4.5.4. Hydrology

The hydrology of southern Africa is inherently subject to extremes. The ratio between the maximum flood and the average flow of a particular river can often exceed 2 000. On some rivers, several years can pass without any significant flow, followed by a single year of several severe floods. Spillway gate operation procedures can change significantly from the "normal" and it is often possible to experience floods at any time during a wet season of seven months.

4.5.5. Project funding and economics

If a scheme is implemented as part of a foreign aid programme, the operational and economic circumstances are likely to be very different when compared to a dam developed to provide water and/or power to a major industrial development. A rural water supply scheme in an under-developed area will not necessarily generate sufficient income to allow the employment of permanent operating staff, or to ensure adequate maintenance of sophisticated hydro-mechanical equipment. In such circumstances, if constructing a dam with mechanical gates, it would be expedient of the funding agency involved to compile and take responsibility for a maintenance and safety programme and to accordingly allow for the funding of the necessary ongoing commitment.

5. AN EVALUATION OF TYPICAL SPILLWAY CONTROL OPTIONS IN A DEVELOPING ENVIRONMENT

5 1 UNCONTROLLED CREST

The most common spillway type is a fixed, uncontrolled crest and this option presents the least problematic, most reliable and lowest maintenance solution that is largely independent of human involvement and least sensitive to human error and neglect. An uncontrolled spillway generally offers good flood attenuation, requires no power source and cannot malfunction as a consequence of any system, or judgement error Such a system can result in a relatively high flood water surface rise, which might be problematic if the reservoir basin is not well managed, but is generally of little consequence in a rural environment

5.2. MECHANICAL CREST GATES

Various different types of mechanical crest gates are currently installed on dams for flood discharge control. Whilst the most common is undoubtedly the radial, Tainter, or sector gate, other systems often used include fish-belly flaps, drum gates and slab (or flat) gates and each of these systems require mechanical lifting, or lowering, to ensure the ability to safely pass flood flows.

The widespread application of such systems is evidence of the significant cost/benefit advantage often provided. A gated spillway implemented on a major dam, with long flood warning, in tandem with a free discharge spillway, possibly designed with redundant capacity to allow for potential gate malfunction, will often offer benefits well outweighing the associated risks and impacts.

There are many examples of such crest gate installations across southern Africa and the vast majority have proved highly successful in operation. However, there is much internationally documented evidence to highlight the susceptibility of these systems to safety incidents and in several instances the failure of gates to be removed from the path of a flood has resulted in catastrophic dam failure [2]. Furthermore, the risk of accidental opening, as a result of faulty automatic actuation, or operator error, is ever present. A gated spillway can create an artificial flood when high flow is least expected and the benefit of a natural warning system associated with the weather patterns is lost

Gate systems that are raised to increase storage level using hydraulic actuators require power to ensure continuity of pressure and to re-introduce hydraulic pressure, as required. Such systems are particularly susceptible to long power interruptions, although they can be considered safer than certain other systems as they will eventually drop out of the passage of flow if power is not restored. Systems relying on hydraulic pressure, however, require frequent and effective maintenance and such gates are only sensible when implemented and

operated by an organisation with adequate maintenance facilities, skills and budgets. Various mechanisms are typically applied to open gates automatically, as the impounded water surface rises, and among these are buoyancy systems. As such mechanisms are completely dependent on effective maintenance, their application is again only considered appropriate where adequate ongoing funding can assure such maintenance.

5.3. SUBMERGED MECHANICAL GATES

Submerged spillway gates will usually be either radial gates, or slab gates. The safe passage of a flood with such gates is entirely reliant on their dependable operation. Failure of gates to operate will result in overtopping of the non-overspill crest, unless an auxiliary spillway is provided. While it is questionable whether such gates are appropriate at all in an unsophisticated environment without an auxiliary spillway, the incorporation of these gates should be seen as a commitment to ensuring the ongoing and permanent presence of competent, skilled operating and maintenance staff at the dam in question

Major gates located at significant depth can often cause concern to their operators. Sealing under high pressure can be rather precarious and the operators may be nervous of carrying out the necessary maintenance check releases for fear of failure to re-seal on closing.

5.4. FUSIBLE SPILLWAYS

Spillway fuses can take various forms, from fuseplugs and flashboards to fusegates. All fuses function on the general premise of providing additional spillway capacity only during low recurrence probability floods and most systems suffer destruction and/or loss in the process of fusing. Unpredictable operation during overtopping has seen the popularity of fuseplugs diminish in recent years, while technical developments have given rise to the evolution of reliable, low maintenance fusegate systems (see Fig. 4).

When the bottom sill of the fuse is below full impoundment level, a drawback of a fused spillway is the capacity loss incurred should a fuse not be replaced after severe flooding. While the application of a fusible system implies a certain balance of benefit against risk, it is usual to assume replacement of a fuse after activation In the case of a poor community, replacement might not always be possible without external assistance and in such instances the related long-term impacts should be given full consideration before implementation.

Practical constraints will generally limit the height range possible for a fusible spillway and once installed, the fuse is susceptible to wilful sabotage, similar to mechanical gates. Furthermore, a fused spillway cannot match the operational flexibility and pre-release opportunities offered by a mechanical system. When these disadvantages do not represent constraints, however, a non-dependence on power supply, telemetric systems, mechanical maintenance and human intervention make fusegates with an accurate trigger mechanism and dependable operation particularly applicable in an unsophisticated environment.

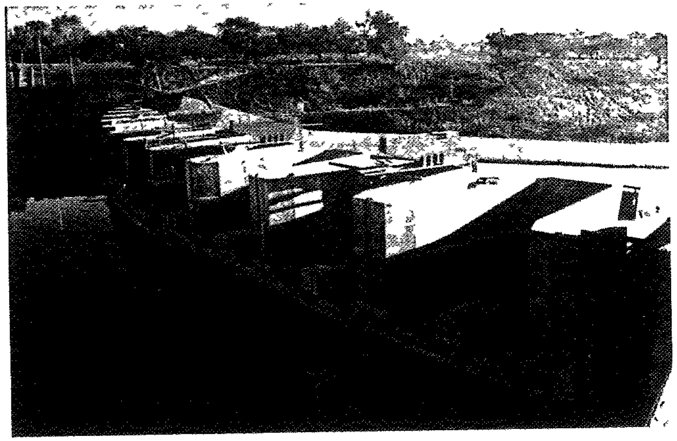

Fig. 4
5 m high fusegates at Kamuzu dam II (Malawi)
Hausses fusibles de 5 m de hauteur, sur le barrage de Kamuzu II (Malawi)

6. DISCUSSION

A good comparison of appropriate gate systems can be made for two dams in Mozambique, Macarretane dam and Pequenos Libombos dam. Whilst the former was completed in 1955 on the Limpopo river (catchment area of 341 320 km^2) as a storage facility and to feed a canal system serving an irrigation scheme, the latter was completed in 1987, close to Maputo. Over the years, the necessary repairs and maintenance at Macarretane have been seriously neglected and the dam was further subjected to military attack and sabotage during the war with Rhodesia (1976 – 1979) Deterioration and corrosion resulted in an almost complete inability to store water, or to feed the irrigation scheme Furthermore, the buoyancy system, intended to lower the 39 gates automatically (see Fig 5 & 6), had become inoperable on virtually all gates, implying that the dam no longer served its purpose of irrigation water supply, while presenting a potentially significant safety hazard, in the event of a flood.

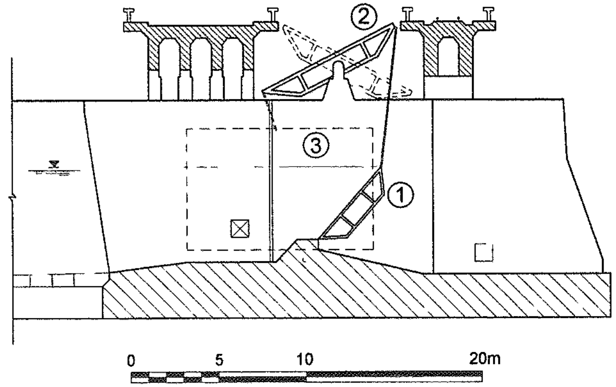

Fig. 5
Cross-section of Macarretane dam (Mozambique)
Coupe transversale de l'évacuateur de crue du barrage de Macarretane (Mozambique)

(1) Hinged gate
(2) Rocker beam
(3) Counterweight float

(1) Vanne sur articulation
(2) Poutre à bascule
(3) Flotteur contrepoids

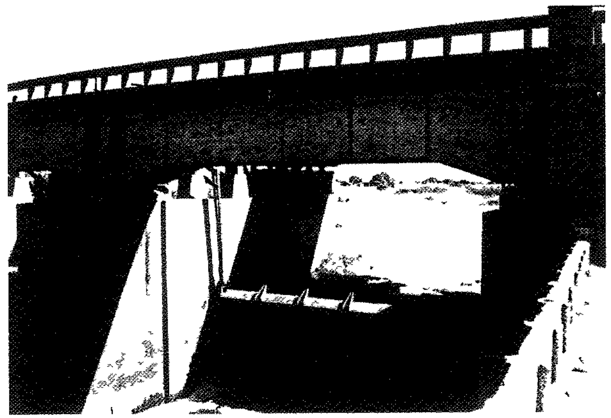

Fig. 6
Macarretane dam (Mozambique)
Barrage de Macarretane (Mozambique)

Initiated in 1996, an externally funded rehabilitation project is currently investigating appropriate measures to re-establish the associated irrigation scheme and to ensure ongoing dam safety.

Pequenos Libombos dam (see Fig. 7) was constructed with a submerged gated spillway, together with an uncontrolled auxiliary surface spillway, with the requirement that the latter should be able to pass the 100 year recurrence interval flood with all submerged gates closed. Should this dam ever be abandoned, the hazard associated with its continued existence would be significantly less than is currently the case for Macarretane and if gate corrosion were eventually to prevent water storage, the safety situation could actually improve, with the empty impoundment providing flood attenuation.

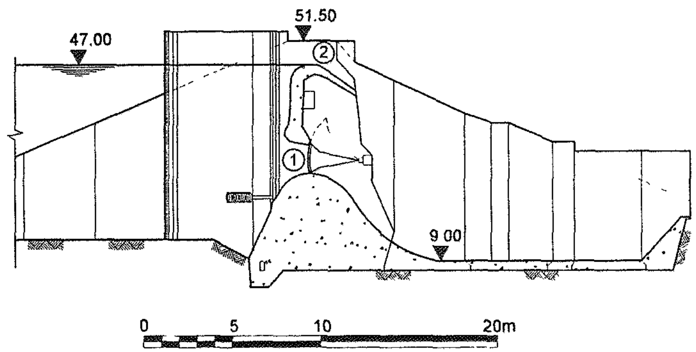

Fig. 7
Cross-section of Pequenos Libombos dam (Mozambique)
Coupe transversale de l'évacuateur de crue du barrage de Pequenos Libombos (Mozambique)

(1) Submerged radial gate of main spillway	*(1) Vanne segment noyée de l'évacuateur principal*
(2) Uncontrolled auxiliary spillway	*(2) Déversoir auxiliaire à seuil libre*

ICOLD warns of the risks inherent to mechanical spillway control and states in their 1987 Bulletin 58 on spillways for dams:

"Regarding reliability of operation, the designer must weigh the risk of one or more gates failing to open when the flood arrives because of power failure to the hoisting mechanism or a gate or gates jamming through faulty maintenance. He must also consider the possibility of human error in opening the gates at the wrong time, or too late because the operating rules are misconstrued. The operator must have ready access to the gate controls at all times. It must be realised that an exceptionally large flood may cause panic. If there is the slightest doubt on the reliability of gate operation or the competence of the operating staff, the wise choice is for an ungated spillway."

In relation to the last sentence of the above statement, and against the background of the preceding discussion, it is suggested that it is only in the more sophisticated environments of southern Africa that a mechanically gated spillway can currently be considered truly appropriate.

7. CONCLUSIONS

The above discussion is not unique in raising the awareness of dam engineers to the risks and hazards potentially associated with gated spillways. However, the circumstances and environments that are common in a developing region are not always obvious to practitioners based in the developed world and the primary objective of this paper is to highlight the important aspects that should be given consideration in any complete review.

A dam with an uncontrolled crest represents a solution that the designer can implement in all manner of circumstances with very little susceptibility to unforeseen risks. Specifying gates on a dam, however, implies that the designer must ensure that all actual and potential risks and eventualities have been identified and addressed, which will require a complete socio-economic analysis of the environment in question, present and future.

In the right circumstances and where the necessary systems and organisational structures are in place and are strong, the implementation of mechanical gates on a dam can offer regional benefit through employment opportunities and social development. In a remote and unsophisticated environment, however, where continuous power supply, effective mechanical maintenance and well trained operational staff cannot be assured, if a fixed crest is not a viable option, the designer should give careful consideration to alternative solutions, such as a dependable fusegate system, before specifying mechanical gates.

REFERENCES

[1] ICOLD Bulletin 58 1987. Spillways for Dams.
[2] WATSON M.A (1997): *Spillway Gates: Will they open safely?* Transactions of the 19th Congress (Vol. 4, Q.75-R.4, pp.49-65). Florence, Italy: ICOLD.
[3] KLEIVAN E. & TORBLAA I. (1988): *Opinions on ungated vs gated spillway for embankment dams.* Transactions of the 16th Congress (Vol. 4, Q.63-R.9, pp.97-106). San Francisco, USA: ICOLD.

chamber, a particular problem was to mobilize the entire kinetic energy for the supply of the inlet well. The adjunction of lateral deflectors, visible in Figure 6a), revealed to be very effective in this case and were adopted for the gates construction.

Qualitative tests performed with floating debris put in evidence that an accumulation of wood trunks behind the fuse gates could affect the tilting conditions. In order to warrant the required functioning, it was decided to install a floating beam shortly upstream of the spillway.

The operational reliability of the fuse gates under normal and exceptional conditions was examined when considering the influence of seal leakage. The hydraulic model tests put in evidence the importance of a good imperviousness of the horizontal joints and the necessity to provide a good planarity of the foundation slab.

6. SPILLWAY CONSTRUCTION

6.1. Civil works

The civil works [6], [7], started in 1997 with the dismantling of the existing gates and the demolition of part of the civil structures down to the rock foundation. A stoplog was installed to protect the job site from the reservoir. In case of an exceptional flood, blasting of the stoplog would have been necessary to provide the necessary discharge capacity to prevent a dam overtopping.

Figure 10 shows the start of the concreting works on the spillway chute following the completion of the demolition works.

Regarding the design of the modified spillway structure it should be mentioned that the crest of the overflow sill does not follow a Creager shape but is horizontal to obtain the necessary surface for the positioning of the fuse gates as shown in Figure 3.

After the completion of the downstream part of the modified spillway structure, the stoplog was removed and the remaining civil works on the spillway approach zone were completed within one month.

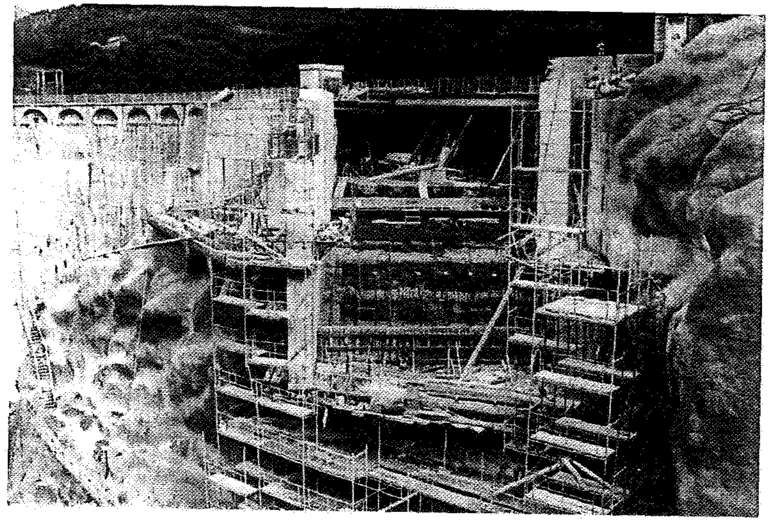

Fig. 10
Downstream view of the concreting works on the spillway chute
Étape de bétonnage de l'évacuateur de crue en rive gauche. Vue d'aval

6.2. Construction and installation of fuse gates

The detailed design, construction and assembling of the fuse gates was under the responsibility of Hydroplus International acting as supplier of the equipment. The fabrication of the fuse gates was subcontracted by Hydroplus to a local supplier. The consultant was charged with the preparation of the technical specifications and the quality supervision during the detailed design and construction phases.

Due to the significant height of the fuse gates and the required planarity of the base joint, it was decided to provide the base of the overflow sill with 200 mm large embedded stainless supports as shown in Figure 11 allowing a fine positioning of the fuse elements.

The fuse gates structures were assembled by welding 10-12 mm StE 37 steel plates locally reinforced with stiffeners to provide the necessary structure rigidity. Relatively small fabrication tolerances had to be respected in order to obtain the needed base planarity and to avoid any blockage of the fuse gate during tilting.

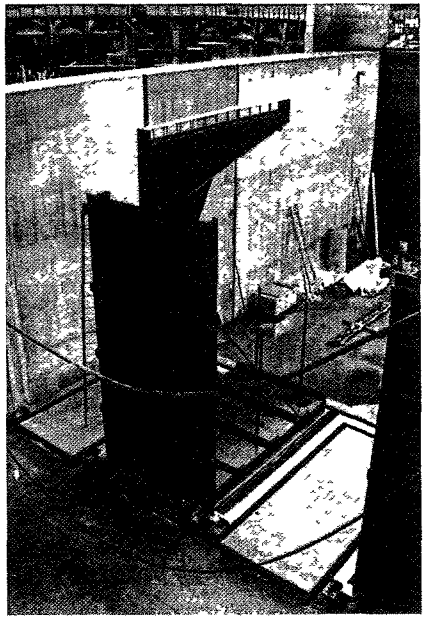

Fig 11
Embedded stainless supports at the base seal of the fuse gates
Supports en acier le long du joint de base des hausses fusibles

The nearly 4 tons steel structures were completely assembled, and painted in the factory prior to be placed by crane shortly upstream of the overflow sill Only after the fine positioning of all four fuse gates, the embedded parts on the sill base were poured and definitely sealed.

Following the positioning of the fuse elements, the base and lateral rubber joints were mounted and the concrete ballast installed on the steel structure, increasing the final weight of each fuse element to nearly 20 tons

To prevent the formation of ice in front of the fuse elements with a consequent modification of the horizontal loads, a water aeration system was provided at the base of the fuse gates. The circulation of water induced by the upward moving air bubbles avoids the formation of ice on the water surface in front of the gates.

A floating beam located shortly upstream of the spillway and moving along two vertical piers is used to prevent the impact of floating debris on the skin plate of the fuse gates. Furthermore, after the tilting of one fuse element, the floating beam avoids the blockage of the hydraulic section by debris.

Finally, the costs for the detailed design, fabrication and installation of the four Hydroplus fuse gates including joints, and spare parts were of CHF 480 000 - (US$ 320 000.-) The costs for the embedded parts and for the supervision during the fabrication and installation may be estimated of approx CHF 50 000 - (US$ 35 000 -)

7. CONCLUSIONS

The necessary increase of the outflow capacity of the Montsalvens dam has been achieved by the installation of four Hydroplus fuse gates. This technical solution revealed to be the most suitable among various design alternatives. The main arguments for that choice are related to the operational reliability and to the construction and maintenance costs.

The experimental investigation of the project on two hydraulic models allowed to optimize its design and functioning. Important modifications could thus be provided, particularly concerning the tilting sequence of the fuse gates and the water jet deviation on the ski jump downstream.

Due to the fact that the surface profile near the gates is significantly affected by the first cleared openings, the last two tilting fuse gates had to be equipped with a surge chamber installed on the well supplying the pressure chamber located at the base of the gates. This technical modification represents a major innovation of the Hydroplus System.

The project will thus satisfy to all the severe safety conditions imposed by the Swiss dam supervision authority.

REFERENCES

[1] BREMEN R., LAZARO Ph (1997). Interventions sur le barrage de Montsalvens. Conférence sur la réhabilitation des barrages du canton de Fribourg, EIL – Fribourg, Suisse.

[2] Entreprises Électriques Fribourgeoises. (1928). L'usine de Broc et son bassin d'accumulation (lac de Montsalvens), Bulletin technique de la Suisse romande, Suisse

[3] Commission Suisse des Grands Barrages. (1946). Mesures, observations et essais sur les grands barrages suisses, 1919-1945, Publication de l'inspection fédérale des travaux publics, Berne, Suisse.