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DESIGN OF ADAPTIVE HYDRAULIC STRUCTURES
(DESSEIN PRÉPOSITION ADAPTER HYDRAULIC STRUCTURER)

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ABSTRACT

As dawn breaks on the 21st century, humanity is confronted with three fundamental problems that are interrelated in a complex system: water crisis, flood mitigation and development of sustainable projects. In view of these challenges, rapid construction of cost - efficient and safe hydraulic structures is vital. On the other hand, hydrosystem changes have resulted in uncertain design parameters. Consequently more efficient approaches should be adopted for design of hydraulic structures.

Solution of these problems will above all require adopting a holistic approach emphasizing the importance of the whole and the interdependence of parts for development of adaptive design strategies. The system of hydraulic structures consists of hardware (structures) and software (management and knowledge). The interdependence of structural and non-structural approaches in design is not well established in spite of the fact that it can reduce the hardware substantially. Using numerous researches and worldwide experience, interdependence of various disciplines of design, construction and operation of hydraulic structures is established and the strategies of the holistic design are developed. Holistic design is based on comprehensive management and flexibility. Accordingly design of the management would be a priority. Continuous monitoring of the hydrosystem and structures is the key to coping with uncertainties of design parameters and consequently seasonal characteristics and forecasting can be incorporated into the design. Continuous management and flexibility would make continuous design feasible. In view of certainties

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and economical considerations, during extreme events far larger than design parameters, the structures should be "designed" to enhance safety. As the last line of defense, safe evacuation of people and property should be ensured. Integration of these strategies would result in reduced structural dimensions and increased safety. Worldwide experience clearly demonstrated that overlooking of these fundamental principles has produced most of the failures, accidents and problems of the hydraulic structures. In the last 10 years, numerous case studies studied not only verified the effectiveness, adaptability and versatility of KURIT but also confirmed the validity of the strategies of the holistic design.

Keywords: Hydraulic Structures, Holistic approach, Floods, Uncertainty, Water Crisis.

INTRODUCTION

The most important challenge of hydraulic structures engineers in 21st century is to design and Construct Safe and Economical hydraulic structures (low cost and short construction time) with uncertain design parameters. Coping with uncertain design parameter is not new for water engineers. Still in recent years hydrosystem changes especially climate change have considerably increased the magnitude of design parameters uncertainty. Solution of these problems will above all require a holistic approach and dependence on risk based approaches and recognition of effectiveness and adaptability of nonstructural risk reduction measures. In this context hydrological safety needs special attention. The increased population of floodplains has amplified the consequences of inundation and on the other hand all over the world larger floods are observed. Consequently the risk of flooding has increased and more efficient approaches should be adopted for design, construction and operation of hydraulic structures.

1. HOLISTIC DESIGN OF HYDRAULIC STRUCTURES

A Doctoral dissertation entitled 'holistic design of adaptive hydraulic structures' was presented in 1997 (Emami, 1997). The main strategies of the holistic design are to:

- Ensure a flexible and adaptive design in view of hydro systems changes and the inherent uncertainties of water engineering.
- Establish the interdependence of hardware (structures) and software (management and knowledge) in design.
- Adapt to the stochastic nature of river flow by integration of seasonal characteristics and river forecasting.
- Design hydraulic structures to adapt to extreme events far larger than design parameters and remain inherently safe (structural ductility).

- Base the design on comprehensive management and flexibility.
- Enhance safety by 'designing' crisis management preceding the events and in real time for the structure an downstream population centers.
- Monitor hydro system and structures on a continuous basis.

Using FAST (Function Analysis System Technique) which is one of the main features of Value Engineering methodology, the Holistic design strategies are shown in Figure 1. F.A.S.T. is used for distributing the system high level function (Design Adaptive and robust hydraulic structures) to the lower function. FAST is a powerful mapping technique that graphically models projects, products and processes in function terms and identifies function dependencies. It is an organized structure ideally suited for exploring complex issues. FAST identifies, in a step-by-step method, required functions, dependencies and the means to arrive at those functions.

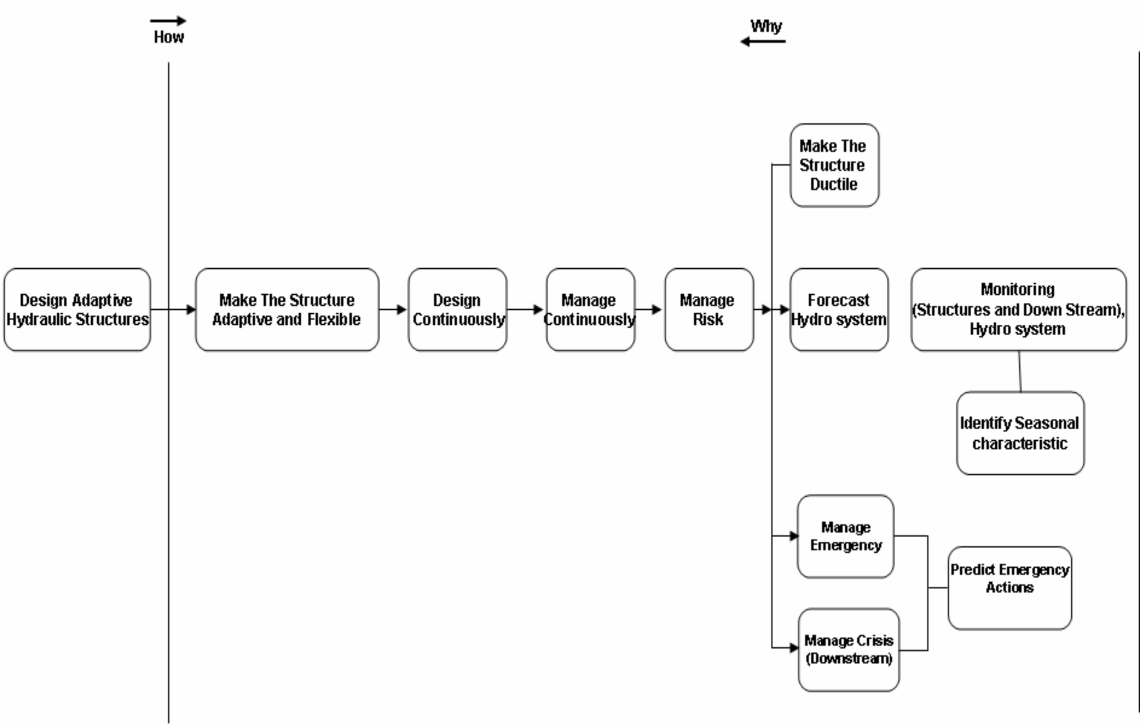


Figure 1. FAST diagram of Holistic Design of Adaptive Hydraulic Structures
(**Le schéma 1**. Diagramme FAST de la conception holistique des structureshydrauliques adaptatives)

According to the FAST diagram to cope with uncertain design parameters and enhance safety we should make the structure adaptive and flexible by continuous design and management. Accordingly we manage the probable risk during the life cycle. For risk management we should be able to forecast the hydrosystem by monitoring the hydrosystem. On the other hand the structure should be able to adapt to extreme events far larger than design parameters and remain inherently safe (structural ductility such as an overtopping resistant cofferdam). Furthermore we should be able to manage the emergency situations in the structure by being vigilant and using Emergency Action Plans (EAP). Finally as the last line of defense in extreme cases the crisis management in the downstream and safe evacuation of people at danger should be planned in advance by Emergency Action Plans (EAP). All the different strategies presented have been used in many projects but the integration the strategies would result in considerable synergy that can resolve the conflict of safety and economy in many cases.

KURIT EXPERT SYSTEM FOR HOLISTIC DESIGN OF HYDRAULIC STRUCTURES

To implement the tactics of holistic design of dams, KURIT expert system was developed based on worldwide experience (Figure 2)(Kurit historical dam was the highest dam in world for 550 years till early 20th century). KURIT is designed to prevent overlooking of fundamental principles of holistic design of hydraulic structures. KURIT presents strategies and guidelines for enhancing dam safety, optimum reservoir sizing selection of design flood and initial reservoir elevation and reducing the conflicts in multi-purposed projects. To justify the guidelines and recommendations and for detailed description of the proposed methods, KURIT presents numerous references. Numerous case studies presented not only verified the effectiveness, adaptability and versatility of KURIT but also confirmed the validity of the strategies of the holistic design. As an example, implementation of holistic design strategies in early impoundment of reservoirs resulted in Fuse shell, an innovation in dam construction.

Development of KURIT is the first step towards a comprehensive expert system for holistic design of adaptive hydraulic structures. Numerous expert systems and an extensive knowledge base should be included in later versions. (Emami, 1997)

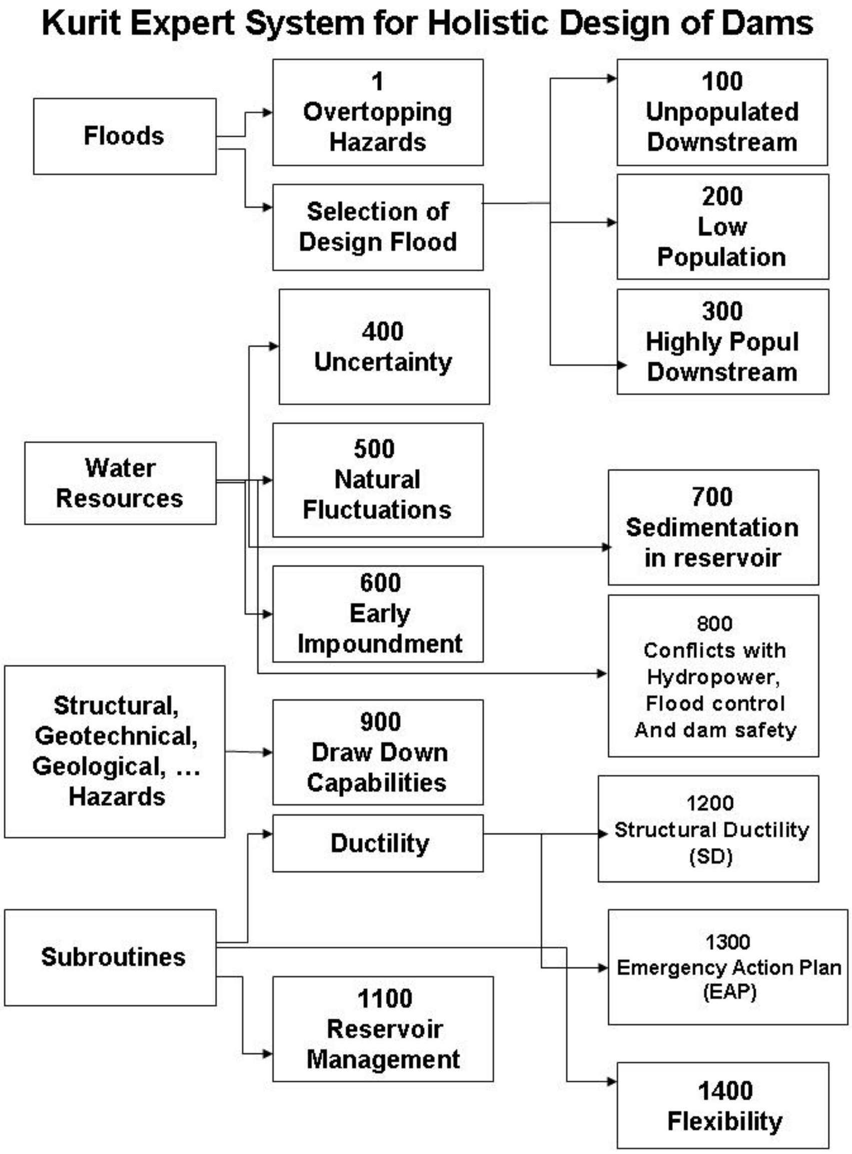


Figure 2: Kuirt Expert system for Holistic Design
(**Le schéma 2:** Système expert de Kuirt pour la conception holistique)

2. NON-STRUCTURAL RISK REDUCTION

In 1990's, the non-structural approaches to flood management were established in many countries and sole dependence on structural methods for flood mitigation was regarded as ineffective. (ICID, 1999). The same trend is developing in dam engineering. The Committee on Costs of ICOLD presented a paper entitled "Nonstructural risk reduction measures; Benefits and costs for Dams" emphasizing the capabilities and cost-effectiveness of nonstructural measures for reducing the risk of dams in Beijing conference in 2000. The committee has published a bulletin on the subject in 2001. According to the bulletin those responsible for dams and their operations should continually search for ways to minimize risk because of the great consequences of dam failure. There is also a responsibility to provide and operate storage facilities in an economical manner. It may be possible to achieve desirable risk reduction through application of nonstructural measures as less costly alternatives to structural modifications. The bulletin focuses on risk analysis, training, structural monitoring, emergency planning, early warning system, and modified operation (ICOLD, 2001). The great Tsunami of Dec. 2004 tragically illustrated the vital importance nonstructural risk reduction measures, real-time monitoring and risk management. It is estimated that with a moderate Tsunami warning system and an appropriate Emergency Action Plan, more than 200,000 lives could have been saved.

3. CASE STUDIES

3.1. Sistan flood management project

The history of floods and droughts in the Sistan plain extends to hundreds of years ago. During the past fifty years, major floods have occurred in 1957, 1982 and 1991 with tens of millions of dollars in total damage and unimaginable human suffering. The droughts for their part have prevented the development of this impoverished province. For example, the notable drought of 1971 was so severe that 70 percent of the population was forced to migrate to other provinces. Chahnime off-channel reservoirs, constructed in 1980, effectively prevented a similar disaster during 1984-1986 droughts.

After the floods of 1991, two alternatives were proposed for flood mitigation of the Sistan plain. The first one was an option of flood control through huge levee construction. The alternative scheme was based on holistic approach and called for addressing drought and flood problems by construction of more reservoirs and diverting the flood peak into the reservoirs by using nonstructural approaches. The scheme would have resulted in enormous saving and reduced construction time, nonetheless, financed by the world bank, the flood control levees was constructed after 7 years. When the worst drought in the history of the region began in 2000 and extended for 3 years, it became apparent what the region needed most were more reservoirs and holistic thinking. The Sistan River with an average volume of 2300 dried up for 3 years. The drought was so severe that the irrigation area decreased from 100,000 to less than 10,000 hectares. Again Chahnime reservoirs, effectively prevented population migration disaster during 1984-1986 droughts.

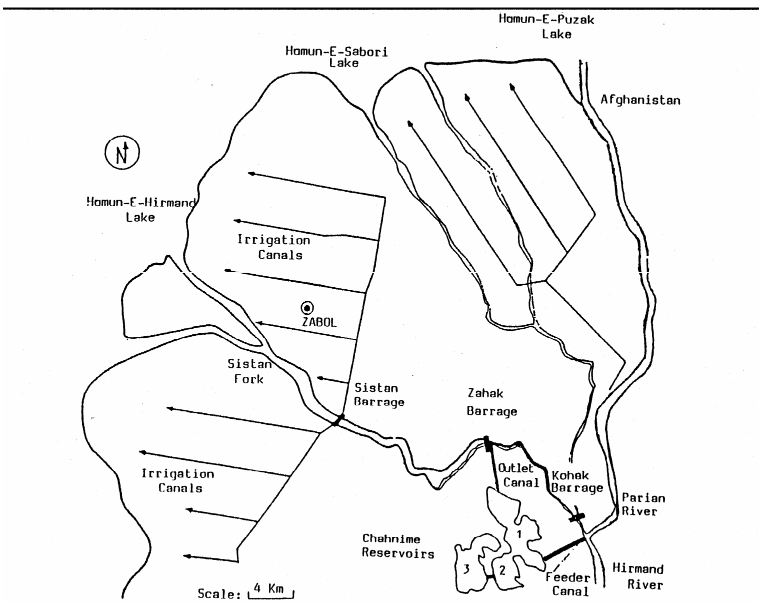


FIGURE 3: General Map of the Sistan Region
(**LE SCHÉMA 3:** Carte générale de la région de Sistan)

3.2. Early Impoundment of Marun dam

In View of water crisis in the world and economic considerations, impoundment of reservoirs during construction can be very important especially for large dams in developing countries. Using seasonal characteristics and forecasting models the first filling can be achieved after the flood season. But the spillway should be in service before the next flood season. In the course of a research on early impoundment of 165-m high Marun dam in Iran, application of holistic design strategies resulted in an innovation that would enhance the safety and flexibility of the first impoundment which is the most dangerous period in the life cycle of a dam. A thin concrete shell was proposed for plugging of diversion tunnel, which could readily be exploded if required to reverse the impoundment. The concrete shell was appropriately called fuse shell. The fuse shell would enhance the flexibility of the design especially in view of common uncertainties of water engineering. Unfortunately the fuse shell idea was not implemented for the first filling of Marun dam in March 1996. So when unexpected leakage of more then 7 m^3/s occurred during the filling (figure 4), the 10-m long concrete plug lacked the desired flexibility. The fuse shell could have saved the day. It could have ended the crisis in 2 or 3 days instead of 6 months. The probability of piping in the core, the delay in construction activities and the environmental damages to the fishes after the explosion of the gates could have been avoided. In practice, the first application of the fuse shell was in another Iranian dam, Godalandar on Karun River for the first impoundment in Dec. 2000. Unlike the Marun project, there was no need for explosion of the plug in the first impoundment of the Godalandar dam in December 2000.

However, the existence of the fuse shell gave the owner and the consultants the assurance required for a safe and flexible impounding scheme. (Emami, Karampoor, 2002b), . (Emami, Karampoor, 2005).

Figure 4: Marun dam after first filling
(**Le schéma 4:** Barrage de Marun après le premier remplissage)

3.3. Value Engineering of Marun Regulatiing Dam

Marun regulating dam (Marun-II) is being constructed 5 km downstream of Marun dam in South-West of Iran. Marun-II would regulate the power plants outflows of the Marun-I dam for agricultural purposes that are the main objective of the Marun system project (Fig.5).

A 6-month value engineering study of Marun-II (a regulating dam downstream of 170 m high Marun-I dam) was undertaken in 2002. Based on the Holistic Design strategies, when Marun-I acts like a mother supporting her child (Marun-II) during construction and operation, a substantial decrease in design floods for spillway and diversion system would be resulted (approximately 80% in both cases). The sharp reductions of the design floods were resulted from the studies performed in the Development Phase: Dambreak studies, Economical risk analysis and water resources and hydropower modeling of Marun system. Ultimately three alternatives were considered by combining the ideas generated in the Creative Phase. Among them, the RCC option received the best Value Index with approximately 60% reduction in total cost and about 50% reduction in construction time.

Safety during the construction would be enhanced and Marun-II would be overtopping resistant (Structural Ductility).(Emami, 2003)

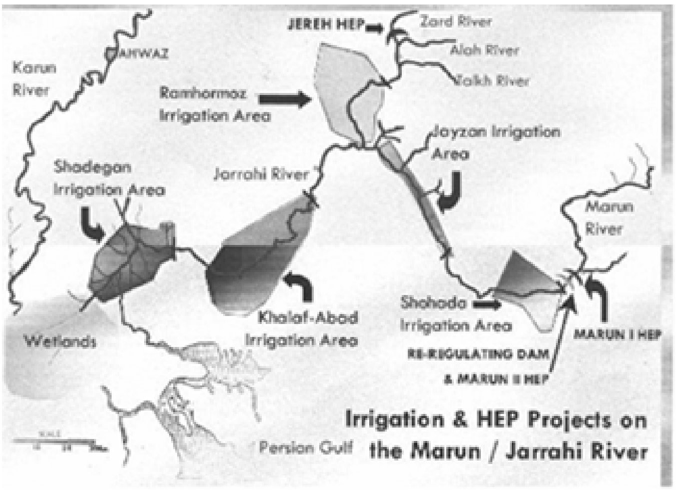
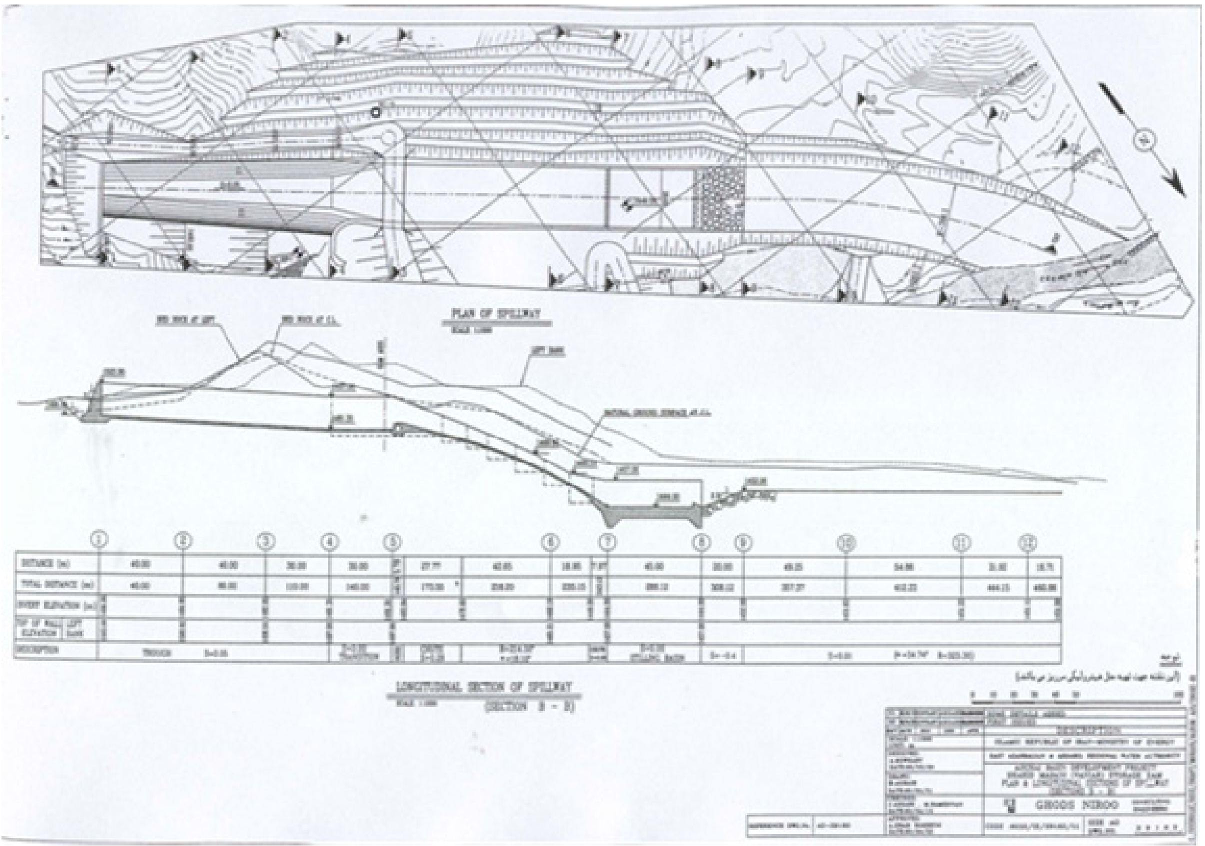


Figure 5. Irrigation and Hydroelectric projects on the Marun-Jarahi Rivers
(**Le schéma 5**: Irrigation et projets hydroélectriques sur les fleuves deMarun-Jarahi)

Value Engineering of Vanyar Spillway

As shown in figure (2) Kurit expert system presents guidelines and recommendations on selection of design floods for spillway of dams. In a value engineering study undertaken in 2003 on the spillway of Vanyar dam in North-West of Iran, the Kurit expert system guidelines on selection initial reservoir elevation in routing of the design flood and season characteristics resulted in considerable reduction of spillway length. The length of side channel spillway, which was 110 m in the base case, was reduced to 40 m when a lower initial reservoir elevation for routing of the design floods in spring for wet years was proposed in the creative phase of the value engineering studies. The water resources modeling of the system demonstrated that if the decision for reservoir drawdown were based on the forecasting model, the draw down would not reduce the regulated flow of the reservoir. The intelligent operation proposed not only decreased the spillway cost by 40% and solved the geological problems at some part of the spillway, but also considerably would reduce the outflows of different floods in Tabriz, which is located just 5 km downstream of the dam. Finally the damages of flood inundation on the reservoir rim would be reduced substantially. (Emami, et al., 2004)



The plan and cross section of Vanyar spillway
(base case, 110 m long side channel spillway)
(Le plan ET la coupe du déversoir de Vanyar (situation de base, déversoir latéral long de canal de 110 m))

4. Summaries and Conclusions

The most import challenge of the water engineers in the 21st century is to design and construct safe and low cost hydraulic structures in the shortest time possible with uncertain design parameters. Solution of this problem will above all require adopting a holistic approach. The main strategies of the holistic design are to:

- Ensure a flexible and adaptive design in view of hydrosystems changes and the inherent uncertainties of water engineering.
- Establish the interdependence of structural and non-structural approaches in design. In this context management of hydraulic structures should designed too.
- Adapt to the stochastic nature of river flow by integration of seasonal characteristics and river forecasting.
- Design hydraulic structures to adapt to extreme events far larger than design parameters and remain inherently safe (structural ductility).
- Base the design on comprehensive management and flexibility.

- Enhance safety by 'designing' emergency and crisis management preceding the events and in real time for the structure and downstream population centers.

In the past decade the holistic design has been used for several water projects including dam construction, flood management and value engineering studies. In all the cases the holistic design has resulted in enhanced safety and reduced cost and construction time. The experiences of application Kurit expert system in the above-mentioned projects are as follows:

1. The large projects are inherently unique; consequently the adaptation of holistic design for each case varies greatly from one to another project. In some cases one or two strategies have more effect on the proposed alternative.
2. Value engineering is an effective tool for achieving a unique solution for a unique project. The creativity phase and job plan of Value Engineering (VE) provide a good base for non-structural proposal. The participation of operation personnel in VE workshops would help the holistic approach of the team.
3. For most cases, the clients and consultants readily accept the holistic approach for early impoundment of reservoirs. In this case the non-structural approach can be very effective.
4. In view of inherent uncertainties associated with determination of design floods, structural ductility has crucial importance in hydrological safety of cofferdams. In this context, it should be pointed out that in the last 15 years, 4 large cofferdams were overtopped and failed in Iran.
5. By presenting various strategies, alternatives and references, Kurit expert system has proved to be an effective tool for holistic design of hydraulic structures.
6. Implementation of holistic design can result in innovations in hydraulic structures such as "fuse shell" for early impoundment of reservoir.
7. The holistic design schemes can also be presented institutively. Still the systematic approach can increase the probability of success.
8. Information technology can greatly help implementing non-structural measures.
9. The tragic experience of great tsunami of Dec. 2004 vividly indicated the crucial role of non-structural measures especially emergency and crisis management.

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