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The Role of C.A.D. in the Design of Major Structures

Le rôle du C.A.D. dans le projet de structures importantes

Die Rolle von C.A.D. bei der Projektierung wichtiger Bauwerke

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SUMMARY
The design of major civil engineering structures, such as arch dams, can be drastically simplified and improved by the use of special purpose graphic packages. In fact in the very preliminary stage there is a need for preparing at a low cost and in a short time a good design in order to be able to closely estimate the cost of the construction (volume to be excavated, quantity of concrete required etc.). Since major civil engineering structures are not built routinely, the experience of the designer is obiously limited and a system for parametric analysis and optimization may be extremely useful.

RESUME
Le projet de structures importantes en génie civil, tels les barrages-voûte, peut être simplifié et perfectionné au moyen de programmes graphiques pour des applications spéciales. Dans une phase préliminaire, il est nécessaire de préparer, avec une bonne approximation, le coût de la construction (le volume des excavations, la quantité nécessaire de béton, etc.). D'autre part, les structures importantes en génie civil ne sont pas des constructions de routine, de sorte que l'expérience de l'ingénieur projeteur est naturellement limitée. Un système d'analyse et d'optimisation à l'aide de paramètres peut être extrêmement utile.

ZUSAMMENFASSUNG
Die Projektierung wichtiger Bauwerke wie Bogenstaumauern kann bei der Anwendung zweckorientierter graphischer Programmsysteme beträchtlich vereinfacht und verbessert werden. Es ist schon wichtig in den frühesten Projektphasen gute Entwürfe billig und kurzfristig realisieren zu können, um die Baukosten (Aushubmassen, erforderliche Betonmenge u.s.w.) genügend angenähert schätzen zu können. Da grosse Bauwerke oft nicht Routinearbeit des Ingenieurs und somit die Erfahrungen beschränkt sind, ist ein geeignetes System für Parameterstudien und Optimierungen sehr nützlich.

1. ROLE OF C.A.D. IN CIVIL ENGINEERING

Computers and programmes for automated analysis and design of structures are a powerful tool for the civil engineering profession. A recent IABSE Colloquium has discussed its role, critical aspects, potential and limitations [1].
It is however obvious that it is very difficult, if at all possible, to speak in general terms about the role of computer aided design and computer graphics in civil engineering: the field of application in mind has to be specified more strictly. In fact, at variance with general purpose packages developed in the sixties and early seventies, interactive design systems are highly application oriented. Moreover programs developed for very ripetitive applications have very different aims that those oriented to one-of-a-kind structures. There is clearly a continuous spectrum which presents on one extreme the building industry where computer is often applied to bridge the gap between pilot project and final design. In this case the aim is to reduce time and manpower during, say, the design of reinforcement or the production of construction drawings. On the other extreme of the spectrum there are more impressing but less frequent civil engineering applications, like dams or containment structures of nuclear power stations. In this case interactive graphic system may be particularly useful in the very preliminary phase ranging from the conceptual study to the preliminary design where the aim is to establish the fundamental characteristics of the structure (say arch dam rather than earth dam) and to choose the most appropriate shape and dimensions.
At this stage very limited information is available about important design data, like rock foundation characteristics, and it is important to compare several alternative designs taking into account economic factors as well: the data used for comparison need not to be very accurate ones. Consequently, very elaborate and costly analyses can be ruled out because the expenses involved would be hardly justifiable. On the contrary there is scope for approximate, quick methods of analysis which can readily accomodate shape and size modifications, as well as parametrization of the ill-known properties. Still the method of analysis should be sensitive enough to detect significant changes in stress distribution induced by modifications of the structural shape or of the foundation deformability.
A critical assessment of the role and potential of this class of graphic system is made more clearly by discussing the particular case of the package GISFADD for analysis of arch dams [2]. The graphic system is based on a very efficient analysis method, a modification of the classical Ritter crown adjustment for arch dams. The modifications suggested by Fanelli take into account torsional and shear effects [3, 4].
Using GISFADD the designer may analyse and compare in a few hours a large number of design configurations (see Figure 1). The semplified method of analysis leads to a compact description of the structural behaviour and this also helps the designer intuition to grasp the

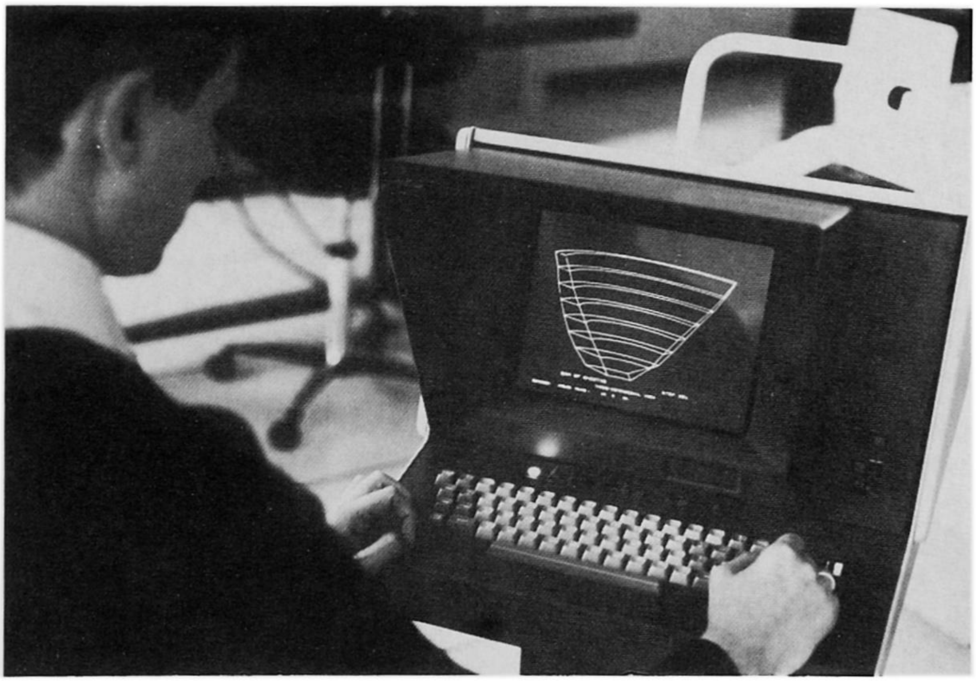

Fig.1 Graphic Interactive System for arch dam design.

influence of the different design parameters
The importance of this fact should not be understimated. At variance with simpler usual structures, very limited learning experience is available to the designer of an arch dam as well as of others structures of the same class. In fact the number of structures of the same kind designed during a lifetime is very limited and moreover little can be learned by failures because they are fortunately very rare due to the high safety coefficient used for any important structure. For instance the total number of arch, arch gravity and double curvature dams built in Italy is 93 out of 485 large dams. However very few have been built during the last fifteen years. Since many of the old designers have now more administrative positions, fresh and available design experience is mainly based on dams designed for foreign countries. This scenario, which is probably common to other European countries, provides a motivation for the development of a tool like GISFADD that enables the designer to educate his intuition to a level accessible to very few individual in the past.
Potential users of GISFADD include regulatory bodies, which may need a quick tool for a first screening of dams designed a long time ago and universities for students attending, say, a Shell Design course. The importance of educating the engineering intuition has grown further in the computer era in view of the need of assessing the accuracy of automated stress analysis [5].

2. ASPECTS OF ARCH DAM DESIGN

Some salient points of the design procedure for arch dams are summarized here for reference in the following paragraph.
The topographical features of the valley are the point of departure for establishing a tentative design of the dam. Usually the designer bases his choice on a comparative analysis of previous designs of dams built in similar valleys and with analogous foundation conditions. Once a frame of reference is established, shape and dimensions of the geometrical elements of the dam, arches and cantilevers, must be defined. This is a long and difficult task because various parameters (radii, angles, thickness, etc.) must be assigned compatible values so as to result in the design of a smooth shell of acceptable shape. The number of reciprocal geometrical constraints imposed by the various elements is very high and additional geometrical requirements arise from the shape of the rock foundation because the thrust of the arches may cause inordinate stresses in the abutments in the presence of an ill designed interface (Figure 2).

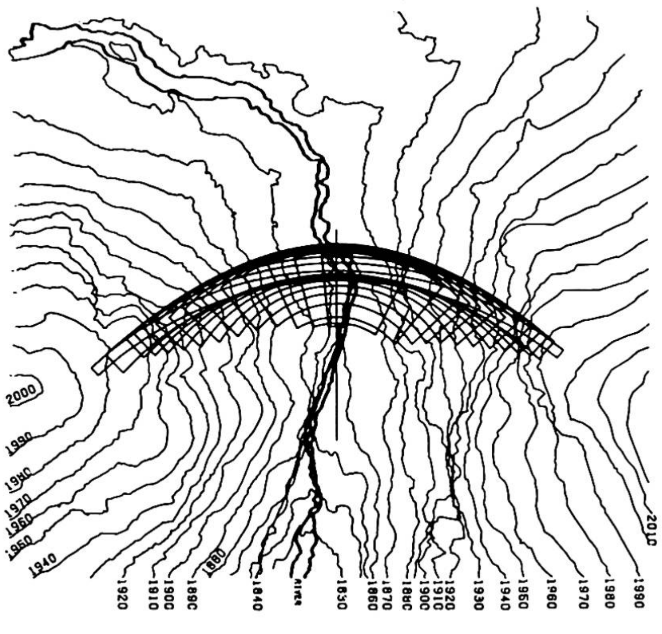

Fig.2 Valley contours and superposed arches of Chiota 's dam.

Moreover several parameters of a merely geometric kind, but with deep implications on the construction process and the cost of the structure, must be kept under control. The most important are the excavation volume and the concrete volume.
Static analysis of the dam used to be a formidable task before the computer era and many more or less simplified computing schemes were developed [3, 6, 7] Still the difficulty of the computation was so high that an unsatisfactory design was more likely to be modified by the designer intuition rather than by a new complete cycle of the design process. Final judgment on the safety of the structure was made by means of a reduced scale model. Nowadays finite element models have come into play but still data

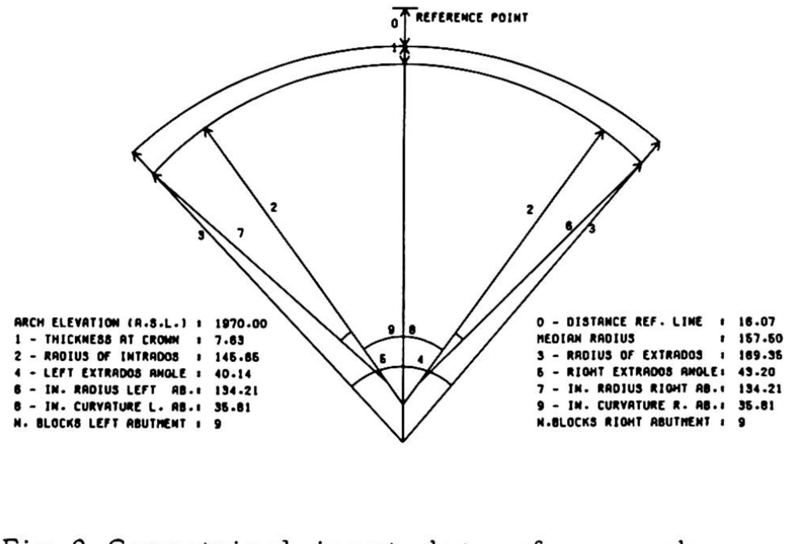

Fig.3 Geometrical input data of an arch.

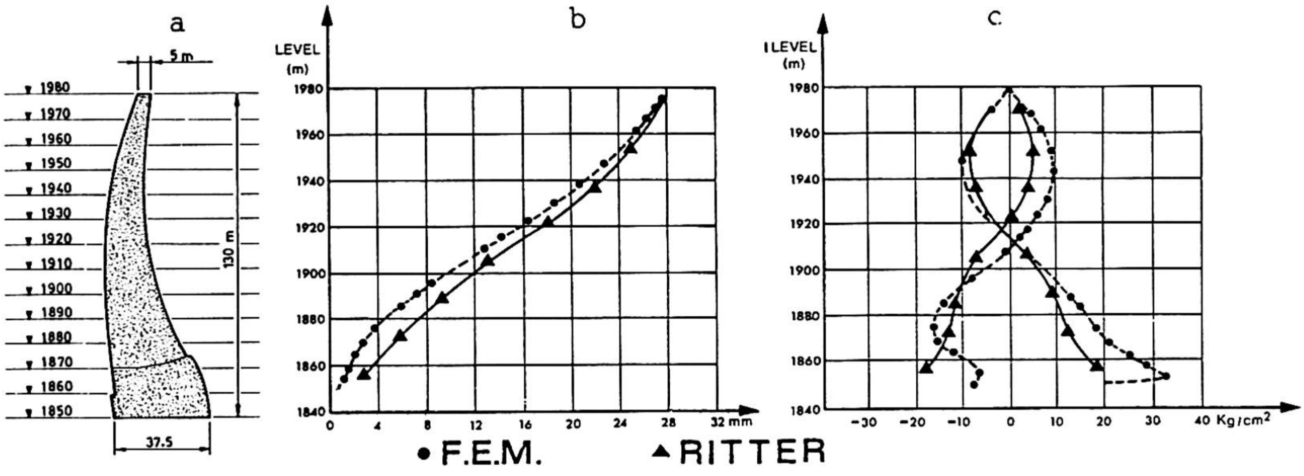

Fig.4 Comparison between results of FEM analysis and Modified Ritter' s method for crown cantilever (a): deflections (b) and vertical stresses (c) under hydrostatic load.

preparation is so expensive that they are not used in preliminary design. On the other hand the old semplified analysis methods can be implemented in the computer and be used for a real optimization process. In addition to be fast and inexpensive, they provide the results in the format expected by the designer and this is a strong advantage over the majority of finite element programs. In fact a simplified method of analysis leads to the computation of stress resultants over the same elements of geometric idealization (arches and cantilevers) used by the designer to set up the model and provides a more direct indication of the remedies to be taken.
Again the graphic post processing capabilities of digital hardware are enormous. Previous considerations do not intend to underestimate the importance of more accurate methods of analysis, on the contrary a good package for preliminary design should have a capability for data output of a finite element discretization of the selected shape so that validation of the results may require little time and manpower. An outline of the role, potential and limitations of numerical analysis of concrete dams is given in reference [8].

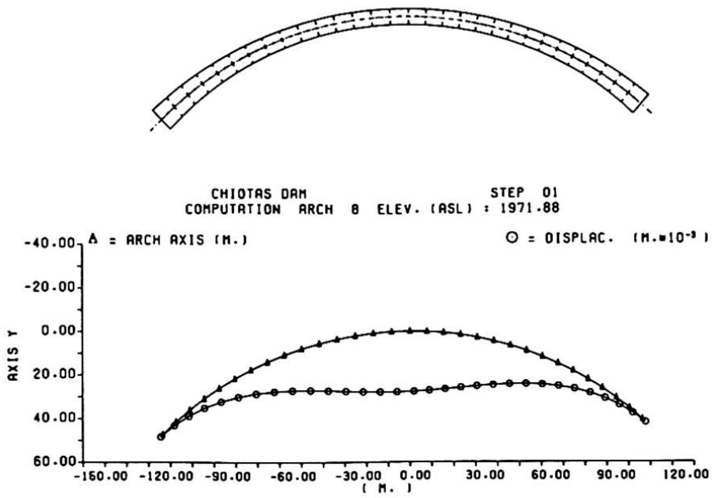

Fig.5 Deformation of central fiber of an arch.

3. INTERACTIVE DESIGN OF ARCH DAMS

In order to automate the design procedure the interactive system GISFADD has been developed at ISMES under support of ENEL/CRIS. The package may analyse arch, arch-gravity and double curvature dams. The main phases of the analysis are the following:

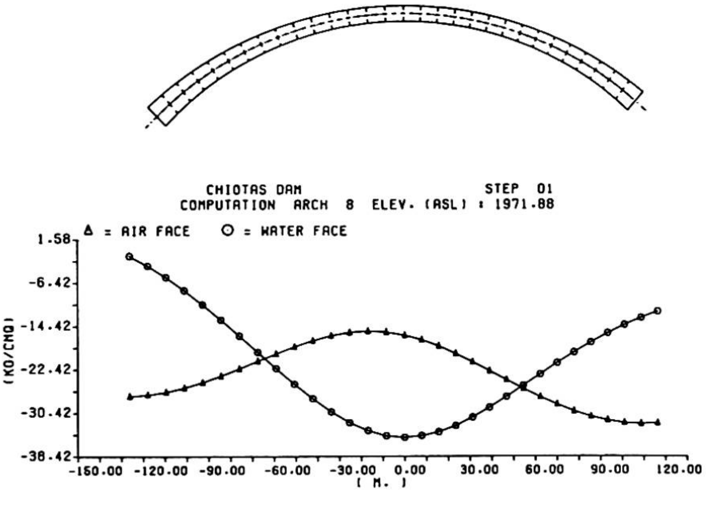

Fig.6 Upstream and downstream hoop stresses of an arch.

- Input of valley contours for visual checking of the static and geometric compatibility between abutments and rock foundation.
- Input of tentative dam geometry through standard design parameters such as upstream and downstream radii and thickness of arches at different elevations (Fig.3).
- Visual check of the geometry: cantilever sections, upstream and downstream developed surfaces, full perspective view of dam, etc.
- Input of loading data and material properties for concrete and rock.
- Analysis for all the basic design load conditions: hydrostatic load, dead weight, concrete shinkage, seismic and thermal loads under

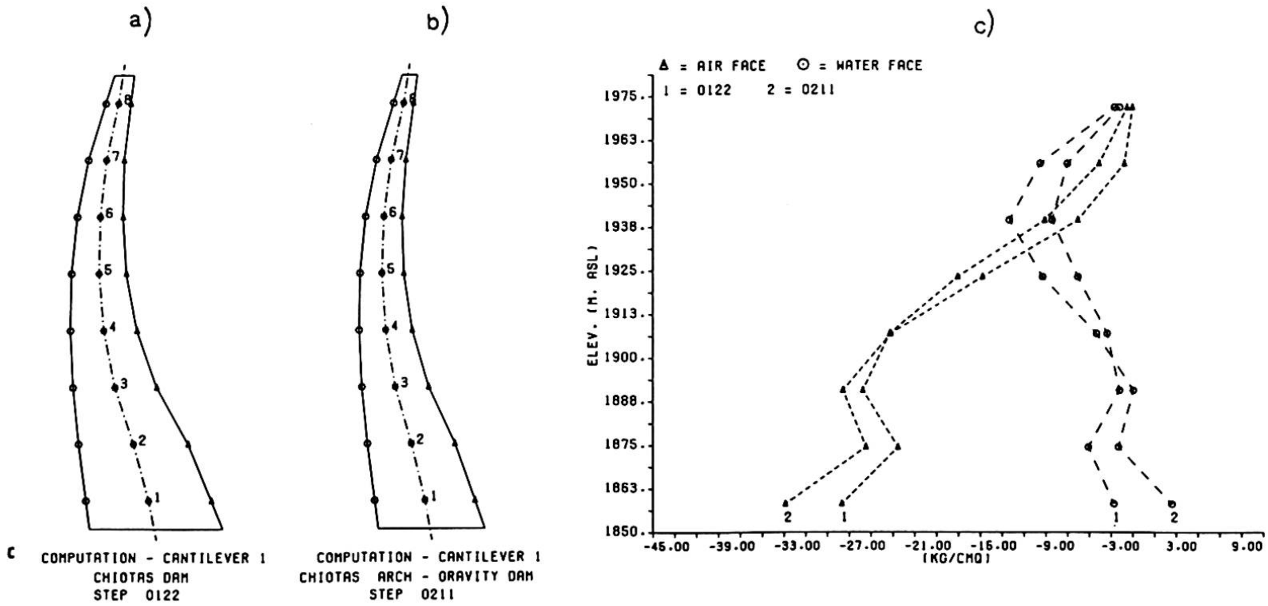

Fig.7 Comparison of vertical stresses (c) due to dead weight and hydrostatic load for two different designs (a) and (b).

both full and empty reservoir conditions. The reliability of the modified Ritter's method has been documented by a systematic comparison of the results obtained for a number of dams by means of the modified Ritter's method, of the finite element method and by physical models [4]. Some results for Chiotas dam are given in Fig.4.

- Deformations: radial and tangential displacements of arches and crown cantilever section (see Figure 5).
- Stresses: upstream and downstream hoop and vertical stresses for arches and cantilever section (see Figure 6).
- Comparison of results from current and previous designs for any load and load combination (see Figure 7).

4. CONCLUSION

Good design usually evolves through the experience gained by the performance of structures. This is typical of, say, building design but applies much less to the design of important one-of-a-kind structures. The reason is that the designer cannot rely much on past experience because of the limited number of structures of that kind available or because of the lack of performance data.
This leads to two conclusions. First important structures should be monitored and the data made accessible. Second once the basic phenomena governing structural behaviour are identified, it may be very useful to apply a graphic system for sensitivity analysis and design optimization. This conclusion has been supported by the case of arch dams, however the conclusions are likely to apply to other classes of structures as well.

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