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# DAMS-AN ENGINEERING ANALYSIS OF ALTERNATIVES

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An attempt has been made to open a debate between two different definitions of science, engineering and technology and therefore about two different perspectives on development. Thus 'traditional' science, wherein the study of side-effects is intrinsic to the solution being obtained, is contrasted with 'modern' science, wherein the study of side-effects is not intrinsic to the solution— as is clear from the definitions, the terms traditional and modern are not meant in the historical sense. The specific example taken for illustration is dam design and the Sardar Sarovar Project (SSP) is contrasted with the Anangpur dam (a thousand year old dam near Delhi). It is shown that from a number of different aspects, hydrological, water logging, deforestation etc., the SSP has been badly designed and poorly executed, while, all the evidence on hand indicates that the Anangpur dam was properly designed and well built. The work thus firmly establishes the need for further study in this direction with a view to rediscovering and developing an engineering method that yields self-sustaining solution and is therefore inherently conducive to the sustenance of the world.

**Keywords :** Design methodology, Engineering alternatives, Side-effects.

## SECTION 1

## INTRODUCTION

This paper attempts to open a debate between different definitions of science, technology and engineering and therefore about different perspectives on development. A debate on engineering alternatives may be carried out at two levels. One would be a discussion of alternatives within a given perspective and the other between alternatives in two differnet perspectives. Here, as stated above, the focus will be on the latter. The modern perspective does not consider a study of its side effects intrinsic to its solutions.

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The term *side effect* is therefore significant. The other perspective would then be one in which a study of side effects is considered intrinsic to the solution i.e. they are not merely "managed" after the design and construction is complete, as is the case in the modern perspective. This we will show to be characteristic of traditional engineering solutions.

As can be seen from the above, the terms 'tradition' and 'modernity' are not meant in the historical sense but are used to indicate the two different perspectives. In the light of this debate the former i.e. between alternatives within a perspective, may be seen as more of a choice between techniques than as one between alternatives . To illustrate this debate between perspectives, the Sardar Sarovar Project has been very much in the news in the recent past, there has been no serious discussion or analysis of it, in academic institutions, as essentially an engineering problem.

In Section 2 the design methodology on which the modern dam is based, is studied and possible flaws in this methodology are highlighted. In Section 3 we describe the Anangpur dam and show how the engineering flaws present in the modern design are absent in the traditional design. Sections 4 briefly discusses some of the engineering side effects of the modern dam and contrasts them with the traditional design. Finally in Section 5 we present the main conclusion of this thesis and indicate the possible directions for future work.

## SECTION 2
## MODERN DAM DESIGN

### 2.1 Methodology

In this section we summarize the various factors/criteria which characterize the process of designing a dam. This summary is based on the design cycle described in a standard text on dam design (Modi, 1988) and a more complete version of the same may be found in Appendix 1. Any other modern source would outline essentially the same procedure.

The design cycle may be broadly broken up into separate but related sections like reservoir planning, site selection, dam type selection etc.

Investigations for reservoir planning include engineering surveys, geological studies and hydrological investigations. Studies relating to storage capacity, waterspread area, suitabililty of foundation for the dam, watertightness of the reservoir basin, runoff pattern, hydrograph of worst flood etc. are conducted. Watertightness of the surrounding hills and narrowness of the river valley at the proposed site are some of the criteria for selecting the reservoir site.

The main criteria for locating the dam are that the length of the dam should be as small as possible and for a given height the volume of water stored should be as large as possible.

Topography, geology, foundation conditions, liability of the region to earthquakes, availability of material and cost are some of the factors which govern the type of dam selected.

The actual process of dam design with reconnaissance of various sites, followed by preliminary investigations. Then in the final stage, site surveys, topographical maps etc. are prepared and planning is done for foundation treatment, rehabilitation etc. and cost estimates are finalised.

Finally we note that the primary (only) parameter used for assessing the viability of a particular design, in actual practice, is the *projected* benefit to cost ratio and great care is taken to see that this ratio is greater than one. In other words the project is *justified* solely on the basis of this cost-benefit analysis. *It must be emphasized that in this analysis all value is necessarily reduced to monetary terms for comparison.*

The SSP has been designed in accordance with the above guidelines. A detailed description of its engineering features may be found in Patil et al., 1994 (Vol. II). Here we will concern ourselves with possible shortcomings of the design methodology and how these related to actual problems seen with the SSP.

## 2.2 Shortcomings in the Design Methodology : Expected Problems

The design cycle on which the modern dam is based has been briefly described in Sections [2.1]. That in case of the Sardar Sarovar Project (SSP) and many other similar projects all of these criteria may not have been given due consideration is not the point of our discussion here. Our objective is to show that the design methodology discussed above is bound to produce a solution which will have various problems associated with it. That is, it is flawed in principle.

2.2.1 The design cycle shows a clear divorce of theory from practice. For example, one of the criteria in the selection of the reservoir site is that the reservoir basin should be water tight. However, no provision is made for deviations from this ideal case—there is no statement in the design guidelines to the effect that 'if the estimated seepage exceeds "x" amount, then the site should be rejected or the design modified accordingly'. It is left to the designer to handle each particular case as best he can. Thus water logging, in the regions surrounding the reservoir, becomes a "side effect", to be managed after the fact.

2.2.2 The design cycle also betrays a lack of understanding of the relationship between surface and underground flows. Thus, while it is known that the presence of the dam will lead to lowering of the water table downstream, there is no method prescribed for the estimation of the magnitude of this problem leave alone prescriptions on how to alleviate it or criteria which tell us when the problem will be unmanageable and irreversible.

A similar difficulty exists in the case of salinity ingress at the mouth of the river due to reduced flows downstream of the dam. Again there is no theory for estimating the magnitude of the problem nor any criterion for deciding when the problem will be unmanageable.

A general conclusion that may be drawn is that there is no overall understanding of the water-air-earth system and hence no theory for gauging the extent of disruption of this system due to engineering interventions. This along with the attitude that whatever problems may arise will be handled by existing or future technology makes for a deadly combination.

2.2.3 As mentioned in section [2.1] one of the primary considerations in dam design remains trapping of maximum water for minimum size so as to get best economic feasibility. The problem is that appraising or deciding the optimality of an engineering solution purely from economic considerations is bound to give unsound answers. This happens because it initiates the process of valuing each parameter in isolation and in monetary terms which is not possible in principle (after all there is more to the value of life than just money value). Even when a certain parameter may appear to be amenable to monetary appraisal, in actual practice, the method to be adopted is far from clear. For example, consider the cost of forests submerged. The Tata Economic Consultancy Services and World Bank calculated the loss by estimating the outrun or sale of various forest produce sold by the forest department. This would mean that if a forest is in a protected zone (say core area of national park), it would haven no "value" (Paranjpye, 1990). Hence calculation based on 'nistar' or trade values is logically incorrect. One possibility is to calculate the 'replacement cost' of the submerged forest (Paranjpye, 1990). Again putting this idea into practice is a very difficult task because the raising of a full forest involves much more than putting up a certain number of trees for timber and some for minor produce. Another suggestion involves calculating per hectare value taking the land (forest) as a productive capital asset, (Paranjpye, 1990) the real value of which must rise over time. This last point raises another fundamental problem with this whole approach and that is: are we to estimate the cost at today's market prices, or at the projected prices when the dam is operational or at the projected prices at some time in the future (say 1000 years hence, since the land will remain submerged and unusable long after the project itself becomes defunct)?

The above paragraph describes a criticism within the modern perspective. However, there are certain costs that are not even addressable within that perspective. The *true* cost of the use of "cheap" fossil fuels and of the use of CFCs in refrigeration, is only now being felt in terms of global warming and the depletion of the ozone layer. Additionally even if a certain area benefits economically from a given project there may be a social-cultural cost associated with this which may well vitiate the economic gain. This of course, is not within the purview of modern science or engineering and is merely a matter for politicians and managers to worry about!! From the traditional point of view this however, would be considered to be *irresponsible/bad engineering*.

Hence there are bound to be incorrect appraisals implying incorrect comparisons and thus the selection of a non-optimal solution. At this point it must be emphasised that the process of judging an engineering solution cannot be assumed to be lying outside the scope of engineering. Engineering by definition means doing things 'optimally' and hence any flaw in the process which determines the 'optimality', is a flaw in engineering. Before moving on to the next point it must be emphasized that the purpose of above mentioned paragraphs is not just to emphasize adverse environmental impacts. What is being emphasised is that these shortcomings are bad engineering in the first place, which of course is bound to have many undesirable (non-engineering) impacts.

It is also clear from the above discussions that while a cost analysis may be useful in deciding between alternatives after the need for a particular project has been properly established, it cannot and should not be the basis on which the project is justified.

2.2.4 The design methodology cannot afford to exclude consideration of the sustainability of the means created by the solution. A non-sustainable engineering solution can be a very bad engineering solution because it may irreversibly modify the very region it serves thus creating bigger problems for the served region later on. This is apart from the problems created near the reservoir and dam site. Most modern dams are by design meant to last about 100 years at best and 50-60 years at worst ! That the design methodology does not even consider this a problem is a serious shortcoming.

## 2.3 Shortcomings in the Design Methodology: Actual Problems

As discussed in section (2.2) the modern design approach has many basic flaws which are bound to create many serious problems. That these problems actually arise is, unfortunately, well illustrated by Sardar Sarovar Project (SSP) and many other similar projects taken in past. A detailed discussion of the existing and expected problems with the SSP may be found in Patil et al. (1994). Here we will consider only a few salient engineering impacts.

In case of SSP as in case of many other similar projects, the problems of water logging and salinity are certain to arise. Interestingly enough, there is no argument or debate over whether these problems will actully arise------there seem to be perfect consensus over this! The point of contention between pro and anti-dam groups is whether through various efforts of planning and management, these problems can be controlled. Water logging in areas around canals will be tackled by methods like lining of canals. A substantial portion of the total command area is unfit for intensive surface irrigation and very much prone to water logging (Patil et al. 1994). Hence an extensive drainage network is being planned along with various other schemes for command area development. That most of the above mentioned plans have failed badly in our experiences with previous projects is not the point here. We wish to emphasize that all these problems arise due to giving engineering clearance to the project thinking that they can be taken care of later by proper disaster management.

Given the way SSP has been designed, the Sardar Sarovar Plan (SSP) published by Sardar Sarovar Narmada Nigam Ltd. ("Planning for Prosperity") says that - " after the irrigation system will become fully operational that is in stage 3, there would be *no water* available in the river bed during the non-monsoon period". This would directly result in the highly undesirable effect of lowering of ground water in regions along the two banks all along the downstream stretch (from Navagam to the sea). Additionally, such a substantial reduction in the river flow downstream of the dam is bound to result in problems like salinity ingress and increased pollution. When the freshwater flow in the river reduces drastically, sea water rushes in, thus the river water will become saline affecting an estimated 75km stretch upstream from sea towards the dam (Seshadri, 1995.) The same phenomena has already been observed in case of some earlier projects. The pollution levels would increase because the contaminant loading (from sources like industries, agricultural use of fertilizers and pesticides etc.) would no longer be carried away to the sea (Seshadri, 1995). Thus what little ground water remains in the regions downstream of the dam is likely to be contaminated as well.

One of the main objectives of SSP is to provide drinking water to the drought prone areas of Kutch and Saurashtra. However, the life of the project is not going to be more than 60 years and project authorities do not think, that is a serious problem since that much time is enough to make what will happen to the increased water needs of Saurashtra and Kutch when the project becomes defunct. These areas (if they indeed get that much supply from SSP as they are supposed to) are bound to develop dependence on the water supply from SSP and when this stops problems are bound to arise (Paranjpye 1990)—problems typical to non-sustainable harnessing and use of land and water. Needless to say, the engineering solution which exploits natural resources in this way is not an example of sound engineering.

### 2.4 The Origin of the Shortcomings

In section (2.2) we discussed some shortcomings in engineering methodology and in section (2.3) we saw how these result in a range of complex problems. At this point it seems pertinent to consider how these flaws creep into our modern engineering practices which have been backed by years of intensive and dedicated research work in so many fields and disciplines. A look at the flaws analyzed in previous sections does give some ideas.

A geologist considers seepage through non-rigid foundations as his only consideration. A mechanical engineer is supposed to have done his task if he can provide a turbine of good efficiency without worrying about how turbine interacts with the surroundings. A civil engineer approves a site if water can be harnessed easily without worrying much about other things related to this harnessing. This is how specialisations are used. The solutions remain good engineering solutions and the engineers are assumed to have done their tasks if their proposed solutions are good in themselves, good in isolation. The system gives the impression of providing optimum efficiency and minimum cost, but it has to pay the price through side effects and ultimately the efficiency is only short lived. For example, the most generous estimate for the life of the SSP would be about 100 years but the Anangpur dam on the other hand is still capable of performing its original function,nearly a thousand years after it was built (see section 3 below). (Put another way, the standard methodology used in science is to solve the equations and then think of incorporating the boundary conditions. Even in the abstract world this sometimes leads to problems as the total character or form of the solution may depend on the boundary conditions---the behaviour of rapidly rotating fluids is a case in point. In applied science the problem could be greater because even the equations to be solved may depend critically on the boundary conditions). But these solutions are embedded in the actual context of a larger system, of which they form a part. If they do not fit well into the whole, they cannot be called good engineering solutions, for the simple reason that they will not prove to be beneficial ultimately. So the crucial part is in understanding the interaction of various elements, various parts of the system and base the engineering solution which due to its very design fits well within the whole system. This does not mean that specialization would go. However the way one poses a problem to himself and also the constraints within a specialisation would change. For example, the civil engineer may be one who specializes in understanding the relationship between land, air and water with respect to dams, while the doctor specializes in understanding the relation between the same elements (earth, air, water and fire) in the human body. Secondly, what is understood by a good and inexpensive solution is not necessarily one that is the "cheapest" to implement at a certain moment in time, but one that does not cause any irreversible changes in nature and one that perfoms its functions with the minimum amount of interference with it. The solutions may appear less efficient, less spectacular/powerful but they have no side effects and are not destructive in their impulse.

An alternate way of viewing the methodology discussed in Section [2.1] is to realise that it begins with a "clean slate" (Uberoi, 1996). That is, the underlying attitude is that there is no order in or purpose to nature other than what is imposed by humans. The water flowing in a river is "going waste to the sea" and it serves a useful purpose only when harnessed to suit our needs. The magnitude and manner of the harnessing is thus limited by the technology available and little else.

Finally, we had observed (section 2.2.1) that the design methodology shows a divorce of theory from practice. One can argue equally well that practice is divorced from theory (Uberoi, 1996) i.e. what is learned from the practice of setting up a dam does not really contribute to the theory of dam building (if it does contribute at all it is to the development of systems analysis or systems engineering). So each dam is a new and separate case. For example, if there are problems in the implementation of Bhakra Nangal it will not be considered a fundamental engineering problem. So when the next dam is to be designed, say the SSP, the same design methodology is used and at best what is learned from the previous experience is how to try and "manage" the resulting problems better.

## SECTION 3
## THE ANANGPUR DAM

### 3.1 Objective

The aim of this section is to study an example of what we have called the traditional perspective of engineering and to see how the underlying principles of this approach are worked into the design of the dam. As we have said earlier, it is the point of view that concerns us not its antiquity, because any "advancement" of science and technology will in the very least have to take account of and contend with this point of view and method of engineering.

## 3.2 Description of the Dam & Site

### 3.2.1 Location

The Anangpur (Anekpur) dam is situated near the village of Anangpur, Faridabad (latitude 28° 28' 40" N, longitude 77° 17' E). To approach the dam one can start from Surajkund and south-west of Surajkund. Following up the stream to the hamlet of Anangpur, one reaches the dam. A location map of village Anangpur (Arangpur) is shown in Fig. 1 and a detailed view of the surroundings is shown in Fig. 2 (both have been reproduced from Archaeological Survey of India, 1950). The dam is behind the village about 1 mile south of Surajkund.

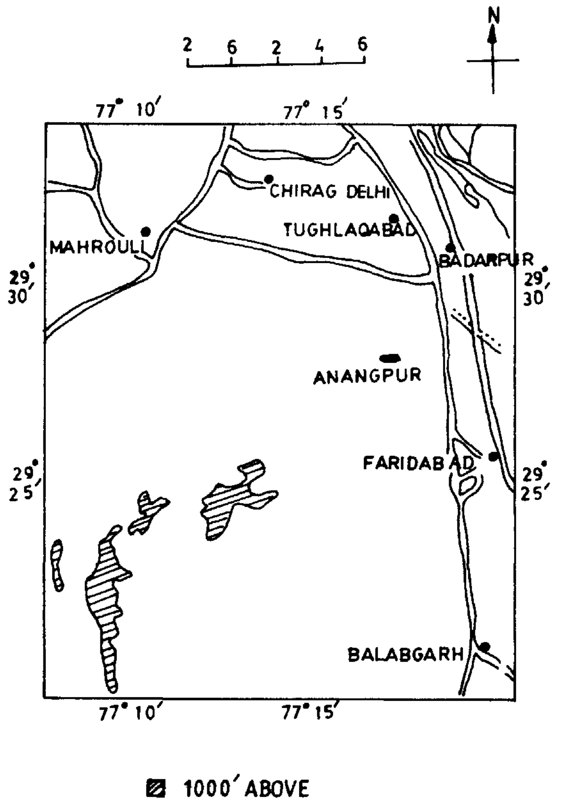


**Fig 1.** Location map showing the Anangpur village (Faridabad district, Haryana) and surrounding areas

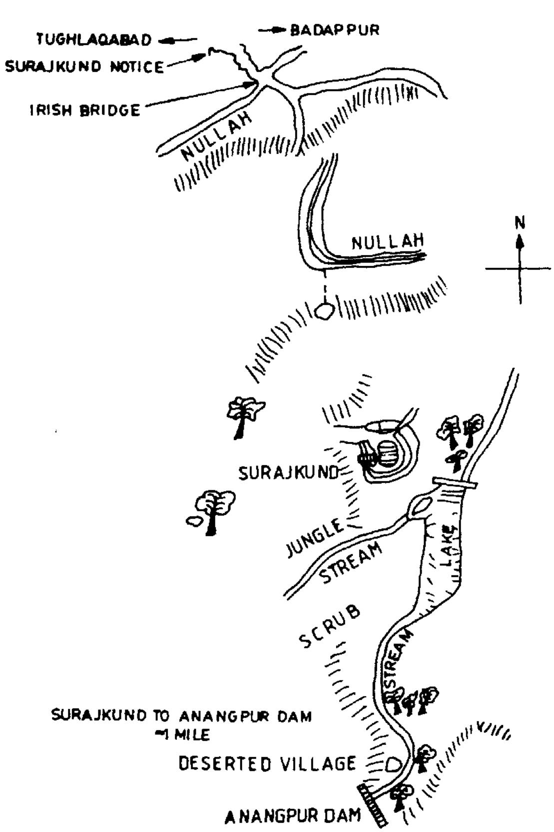


**Fig 2.** Location map showing the details around the Anangpur dam

### 3.2.2. Description of the Dam and Site

The Anangpur dam is a gravity dam made of quartzite stone, believed to be made by king Anangpal I (some sources refer to him as Anangpal II). According to one estimate the village with dam was founded in 676 AD, but according to General Cunningham [an excavator], the dam was built in AD 1051. The material regarding location of the dam and the historical information above have been taken from Annual Reports of Archaeological Survey of India (Archaeological Survey of India, 1950). These reports also touch upon a few engineering aspects but they have not been included here as they are scanty and partly wrong, for example in the reports there appears to be a confusion between the downstream and upstream side of the dam.

The dam has been designed to divide a naturally existing reservoir by being placed at the narrowest portion of the reservoir. Further the location of structure is such that on the downstream side there are vast plain grounds confined by the tails of the Aravali range. During the field visit one could see a small flow emerging at the base of the dam on the upstream side but no corresponding flow was there on the downstream side. This indicates that some underground stream opens up just at the dam wall, on the upstream side, feeding the reservoir. Upstream of the dam is a long reservoir (which widens at its upstream north end into what is now known as peacock lake), lined on the sides by mountains of hard rock. At its extreme upstream end, the reservoir is cut, naturally from the surrounding area by a small impermeable ridge. A structure in the vicinity is the Suraj Kund pond (Fig. 2,) made by Tomara King, Surajpal. These two closely located water bodies do not seem to be connected by any surface flows. Whether there is an underground connection is still to be investigated.

The dam is about 12.1 meters high, 20 meters wide and 103.3 meters long. The drawings of the dam along with the major dimensions are attached at the end of the report (Figs. 3,4 and 5). Fig. 3 shows the view from top and the dimensions of the structures on the downstream side in this view (such as the length and angle of the shoulders) are approximate. At the time of the field visit, there was lot of vegetation on the downstream side and hence it was difficult to measure dimensions accurately on this side. Fig. 4 is the front view of the dam from the upstream side, showing all the sluice channels. Fig. 5 is a sectional side view (partial) showing the difference of 6.4 meters between the water level on the upstream side (at the time of the field visit) and the ground level on the downstream side.

The dam consists of three levels of sluice channels, namely, the top level, the middle level and the bottom level. There are three sluice channels at the middle level and two each at top and bottom level. All the channels are located symmetrically with respect to the centre line of the dam (Fig. 4).

On the downstream side of the dam, shoulder like structures are present (Fig. 3), which start about 0.9 m below the top of the dam and about 3.8 m away from the dam wall, this height of 0.9 m being divided into two steps (Fig. 5). The length of dam wall enclosed between the two top level sluice channels exactly matches the width of shoulder at its starting point (Fig. 3). These two top level sluice channels, instead of venting out directly onto the downstream side, empty into a channel (marked as overflow channel in Fig. 3) along the length of dam, from which water can then overflow.

The central channel of the three middle level sluice channels opens out directly on the downstream side, (at level with the ground on downstream side as shown

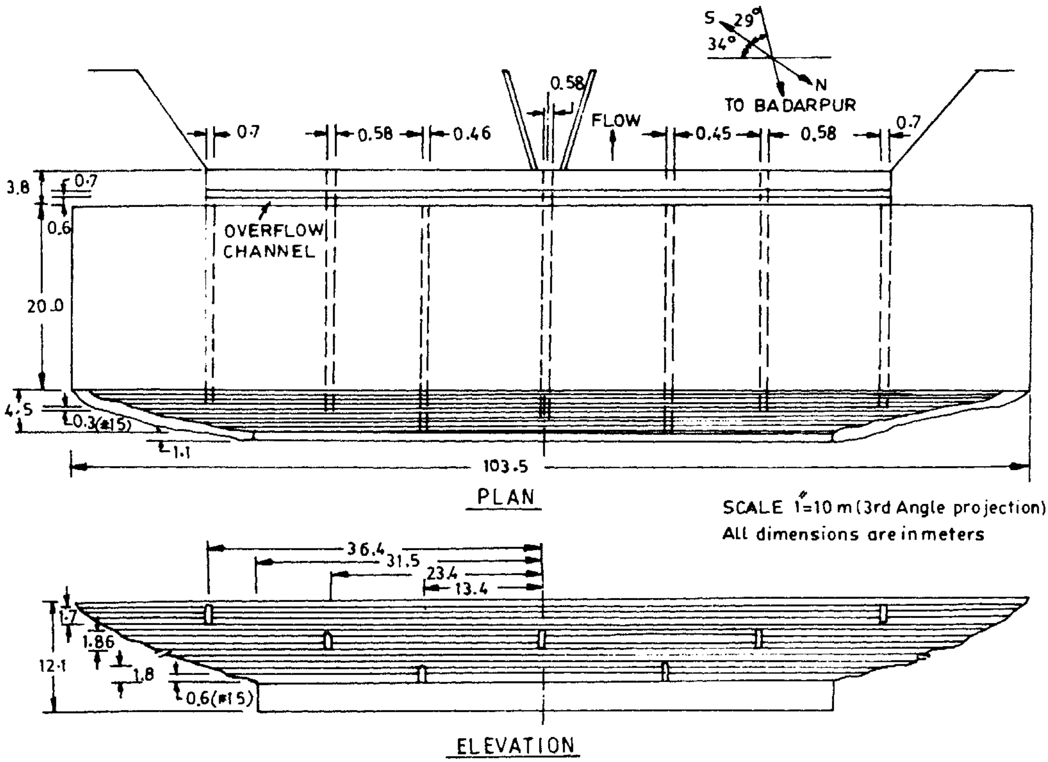


**Fig 3.** Two views of the Anangpur dam

in Fig. 5), into a guiding channel, with constructed bottom and widening as one moves away from the dam wall (Fig. 3). The other two gates at middle level vent out directly on to the downstream side. The ground level on the down stream is exactly at the bottom of opening of middle sluice channel, thus implying a difference of about 6.4m between present water level on upstream side and the ground on downstream side (Fig. 5). It also means that the bottom level sluice channels open below the ground level on the downstream side (Fig. 5). Further the bottom channels have full size openings at the upstream end but at the downstream end there is a slab with four holes, instead of the whole channel opening directly. Next to this slab there is space for movement of sluice gate for closing and opening of holes. Next to this space, again there is an identical slab containing four holes, in line with holes of first slab (Fig. 6), thus resulting in a sandwich construction at the downstream side opening of the bottom level sluice gates. The sandwich construction along with observed difference of ground level would mean that the lowest level sluice channels were used for underground irrigation. The sandwich construction would facilitate easy movement of sluice gates which would get obstructed if sluice gate were to directly rub against the earth. Further the sandwich construction ensures that the earth matter does not obstruct the whole channel as soon as the sluice gate is lifted up. (The higher ground level on the downstream side was mistaken for silting and hence the confusion between the upstream and downstream sides in the archeological survey report mentioned earlier.)

The sluice channels at all the three levels are 1.8 m high although the widths of the gates at different levels, are different. Thus only the width was changed to get different cross-sectional areas for the channels at different levels.

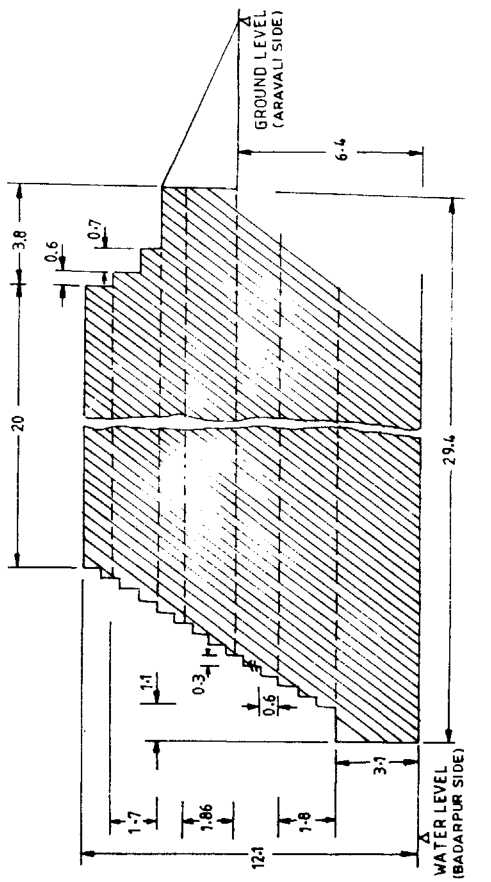


**Fig 4.** Sectional side view of the dam showing the difference in the levels on the upstream and downstream sides

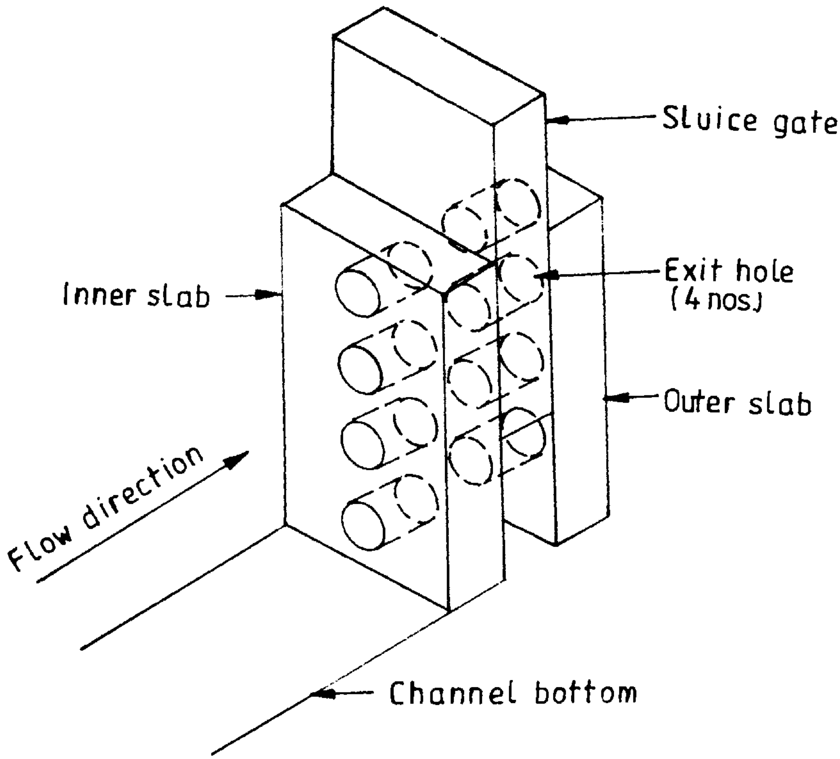


**Fig 5.** Details of the construction of the bottom channel sluice gate

### 3.3 Some Design Estimates

#### 3.3.1 Resistance to Toppling (overturning) and sliding

In the toppling analysis only the major contributions are considered ----the hydrostatic pressure and weight of dam. As it turns out later, the very large factor of safety justifies the assumption that all other contributions (e.g. uplift pressure, earthquake, silt pressure, wave pressure etc.) would not affect the degree of safety of the design much.

#### Location of the Centre of Gravity

First let us consider a simplified structure for the dam keeping all the important engineering features, as shown in Fig. 7. All the dimensions used in the following calculations have been taken from the drawings in the Fig. 3 to 5. The distance of centre of gravity from the heel of a dam on the downstream side needs to be estimated (in order

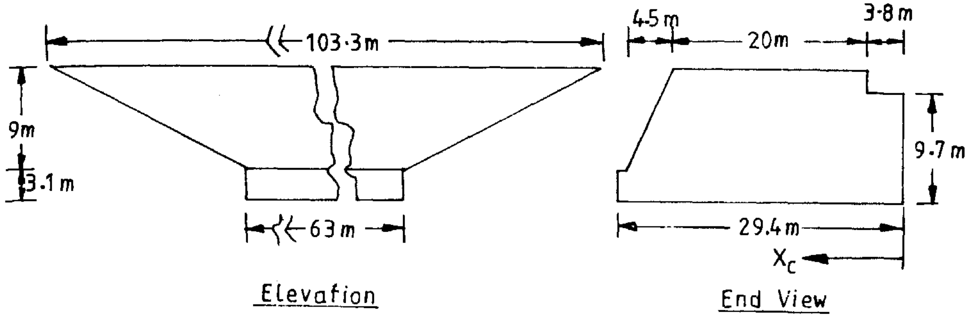


**Fig 6.** Simplified structure of the dam used in the stability analysis

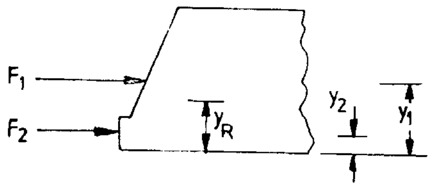


**Fig 7.** Hydrostatic forces on the dam

to calculate later the restoring moment due to weight). The distance of the centre of the gravity from the heel of the dam on the downstream side is:

$$x_c = \frac{(0.5\times9\times4.5\times25.3)+(5.6\times3.1\times26.6)+(12.1\times20\times13.8)+(9.7\times3.8\times1.9)}{(0.5\times9\times4.5+5.6\times3.1+20\times12.1+3.8\times9.7)}\,\text{m}$$

$= 13.9$ m.

Volume of the structure is V' = (29.4×3.1×63) + (4.5×4.5 + 20×9 + 6.6× 3.8) × 83.15 m$^3$ = 24,500 m$^3$

Average volume of any one channel = (1.8×29.4×0.58) = 30.7 m$^3$

Thus the net volume is: V = 24,500 - (7×30.7) = 24,300 m$^3$

## The Hydrostatic Force

This force will be calculated assuming all gates closed. $F_1$ is the force on the inclined portion while $F_2$ is the force on the vertical portion at the bottom. $F_1$ acts at a distance $y_1$ equal to 6.1m from the bottom while, to be conservative we will assume that $F_2$ acts at a distance $y_2$ equal to 1.55 m from the bottom.

We then have,

$F_1$ (max)= $10^3 \times 9.81 \times (9/2) \times 9 \times 83.15$ N = $33 \times 10^6$ N

and,

$F_2$ (max) = $10^3 \times 9.81 \times (9 + 3.1/2) \times 3.1 \times 63$ N = $20.2 \times 10^6$ N

The resultant force then acts at yR given by,

$$yR = \frac{F_1 y_1 + F_2 y_2}{(F_1 + F_2)} = 4.37\text{m}$$

### The Toppling Moment

Thus the toppling moment $M_t$ may be obtained as:

$$M_t = (F_1 + F_2)\ _{yR}\ \text{Nm} = 2.32 \times 10^8 \text{ Nm}$$

### The Restoring Moment

The restoring moment has two contributions—the weight of the dam and the vertical portion of hydrostatic force acting on the inclined surface. However, to be conservative, we can neglect the latter. The density of stone $\rho_s$ may be taken as 2.6 x $10^3$ kg/m$^3$. Thus we can estimate the restoring moment $M_r$ as :.

$$M_r = V\rho_s g x_c = 24{,}300 \times 2600 \times 13.9 = 8.6 \times 10^9 \text{ Nm.}$$

### Factor of safety against overturning

Thus the factor of safety against overturning, $F_{so}$ may be obtained as:

$F_{so} = M_r/M_t = 37$

### Factor of safety against sliding

This factor $F_{ss}$ may be obtained as

$$F_{ss} = \frac{\mu \sum F_v}{\sum F_H}$$

Here again we will obtain a conservative estimate by not including the vertical forces due to water. The coefficient of friction for masonry, stone and concrete varies from 0.6 to 0.75 (Modi, 1988), we can thus choose a value of 0.6 for $\mu$. Thus we have:

$$F_{ss} = \mu V \rho_s g/(F_1+F_2)$$
$$= (0.6 \times 24{,}300 \times 2600 \times 9.81)/\ [(33 + 20.2) \times 10^6]$$
$$= 7.$$

Thus we see that the factors of safety used in the design of the Anangpur dam are very high in comparison to those in use today (cf Modi, 1988). The question that naturally arises is whether this high a factor of safety is just incidental or whether there was a strong rationale behind it. That the dam was well designed and built is obvious from the fact that it is completely intact even today—having withstood ten centuries of operation and natural calamities---and were the reservoir level as before it would *still be functional.* What little damage has occurred is merely from lack of maintenance (like vegetation between stones splitting the region around it) and in no way affects its funtion. If the SSP were designed to last not merely 100 years but several thousand years like the Anangpur dam it is very likely that one would need very large factors of safety there also. (Note that usually, longevity is not related to the factor of safety, however, since we are basing our calculations on the hydrostatic force and nothing else, the longer the expected life, the larger the magnitude of a probable natural disaster and hence the larger should the factor of safety be.)

### 3.4 Salient Features of the Anangpur Dam

3.4.1 The reservoir is surrounded by hard rocks and the possibility of seepage from the sides of the reservoir, due to the increased height upstream of the dam, is very remote. Secondly the rock face is nearly vertical and hence the increased reservoir level would not have led to any extra submergence on the upstream side of the dam.

3.4.2 The sluice channels at different levels have different areas (smallest at the bottom and largest at the top) to account for the difference in head available. However, this difference in area was obtained by changing the width of the channels (e.g. middle level) or by providing holes in a slab (lowest level) instead of keeping the full channel open, while keeping the height constant (approximately 1.8m). Thus the design provided for easy maintenance (the height is obviously designed to allow a human being to stand upright in the channels).

3.4.3 The dam by its very selection of site was meant to fit well into the local topography and make conjunctive use of available underground and surface flows. The dam's location is critical since it is at the narrowest position of an already existing reservoir and such that it just contains the emerging underground flow onto the reservoir side. Thus instead of creating a big impoundment in a naturally flowing river it divided a naturally existing reservoir, creating bigger head on one side so as to create flows on other side which could be used for irrigation purposes. This way, the water resource contributed both by rain and underground flows was harnessed, to serve the local needs. The ability to come up with such a design indicates a detailed knowledge of the interaction of surface and underground flows and the interaction of these flows with other elements and also a deep understanding of the relationship of the dam as a whole to the environment in which it is placed.

An additional advantage of locating the dam just downstream (with respect to the surface flow) of the underground flow is that any tendency to silting at the base of the dam is alleviated automatically.

3.4.4 As mentioned in the section [3.2], the lowest sluice channels were designed to provide underground seepage on to the downstream side. Thus there was a provision for enhancing the ground water on the downstream side. We have noted earlier that the dam split an existing reservoir, thus the presence of the dam was bound to alter (lower) the ground water on the downstream side (where the village benefitting from the dam was located)-----this problem was taken care of by the lowest sluice channels. The important point that needs to be noted here is that the problem was anticipated and handled *at the design stage itself* thus obviating the need for crisis management after the dam was built.

There are several other features that deserve a more detailed study, for example the area that is likely to have been irrigated; the size of the village it could serve; the volume of storage in the reservoir; the porosity of the soil and hence the likely magnitudes of the flows in the bottom sluices, etc. Some of these issues will be looked at as part of our continuing study of the dam, however, some, like the size of the original reservoir, will be more difficult to determine. There has been (and still is) intense quarrying activity in the past few years on either side of the reservoir changing its topography significantly. Thus, unless we discover detailed contour maps of the area, made prior to the rock blasting, a direct measurement of the reservoir size would be very difficult. It is also significant that what nature could not do in a thousand years is being accomplished very easily and efficiently in a few years by humans---already a small structure near the dam has collapsed due to the blasting in the vicinity and the dam may soon follow.

Here we have studied one example of a traditional engineering structure. In the course of the study we have attempted to understand and extract the general principles on which such a structure must have been based. The more straight-forward approach of starting with the general and working out the particular, as we have done in the case of the Sardar Sarovar Project, could not be undertaken primarily because it is very difficult to obtain texts outlining traditional engineering — the few that are available are in Sanskrit and English translations thereof are not easily obtained. However, one aspect that clearly emerges from this study is that no traditional project was attempted without a clear understanding of the interaction between the various elements of nature (air, water, earth etc.) and without an understanding of the relationship of the engineering structure, in question, to the local and wider envirornment. How this is to be worked out in detail is something that needs extensive study.

More such examples would of course strengthen our argument. However, it is clear that this example is sufficient to indicate a method which is fundamentally different in its cognitive presuppositions and practical implications, from those of modern science and engineering.

## SECTION 4
## SIDE EFFECTS

### 4.1 The Sardar Sarover Project

It should be emphasized that in this study the SSP has been chosen not because it is controversial right now but because it is a visible example of what we have explained to be the modern perspective. We have already seen some of the problems with this project in Section 2. There, however, we were concerned more with what we can call 'defects' in engineering methodology and its solutions than with its "side effects".

There is a huge body of literature on the environmental, social and other impacts of the SSP and we will not concern ourselves with reproducing that here. The interested reader is referred to Patil et al. (1994) for a comparatively milder account and to Seshadri (1995) for a harsher account. From either it is clear that a lot of problems have already been felt or are expected. Problems like displacement of tens of thousands of people; submergence of large amount of forest and agricultural land; disruption of aquatic life, and therefore of the human and animal life dependent on this aquatic life, downstream of the dam; destruction of large tracts of prime agricultural land at the river mouth due to salinity; increased pollution downstream of the dam; health hazards from insects that would breed in the large body of stagnant water, etc. The SSP has been claimed to be one of the most elaborately studied and planned project ever. However, it is again quite clear from the references cited above that the measures taken to counter these problems are far from adequate and in some cases the problem is orders of magnitude larger and more complex than anticipated.

This raises two questions:

i) Is the SSP worth the price we will have to pay ?

ii) To what extent is this price a necessary price? i.e. it is intrinsic, not merely to this project or the other development projects but to our definitions of science, engineering and technology?

In partial answer to the first question, even in the U S A, the country where all these engineering solutions were first explored and developed, the impossibility to compensate for all the side effects and hence the unmanageability of big dams has already been realized (Beard, 1994). Moreover, from our discussions above (section 2), it is evident that all these "side effects" are symptoms of a much more fundamental problem. They represent not merely insufficient and inefficient management but presuppose a certain definition of engineering and its relation to nature or of knowledge/science and its relation to the world ---- it is one of conquest ---- the more evolved or sophisticated your knowledge/science, the more efficient your conquest. Of course, this does not imply managing or conquering yourself or your needs. Here development presupposes indefinitely growing need, want and power over nature (external to oneself).

### 4.2 The Anangpur Dam

Section [4.1] discussed the side effects associated with SSP and the difficulties facing action plans designed to mitigate these side effects. The Anangpur Dam, however, was bound not to have many of these problems, in first place, due to its proper design. Thus the whole problem of mitigation plans and disaster management is not an issue for the Anangpur dam.

The Anangpur dam reservoir is surrounded by hills of hard rock which are quite unsuitable for intense vegetation. Further the walls are nearly vertical and thus increasing the height of the water in the reservoir hardly caused any extra submergence. The dam did not impound a large amount of naturally flowing water. Instead from the local topography it appears that it just converted a seasonal extended reservoir to perennial, smaller reservoir. This itself almost completely eliminated the possibility of occurrence of so many serious downstream impacts as in case of SSP. Further the feature of underground irrigation present in the design itself must have taken care of the problem of reduced downstream water table. The problem of silting was at least partially taken care of by ensuring that the underground stream was placed just upstream of the dam.

It is very easy to write all this off as just coincidence or good fortune or simply assume that its small size alone was responsible for the success of the Anangpur dam. The more worthwhile exercise, however, would be to try and rediscover the design methodology underlying the Anangpur dam.

## SECTION 5
## CONCLUSIONS AND SCOPE FOR FUTURE WORK

In Sections 2 to 4 we have seen two engineering solutions, namely the Sardar Sarovar Project (SSP) and Anangpur Dam. Aspects related to SSP have been covered in more detail than the Anangpur Dam, because, due to constraints of time as well as some other factors, detailed data on Anangpur could not be gathered. We have seen that from a number of different aspects, be it hydrological, water logging, deforestation etc., the Sardar Sarovar Project has been badly designed and not just poorly executed. On the other hand all the evidence indicates that the Anangpur dam was properly designed and well built. This difference is not a matter of bad management on the one hand and good fortune on the other. It is clear from the study of the design cycle of the modern dam that really considering the possible impacts that a particular piece of engineering has on the rest of the world is not intrinsic to the self definition of engineering nor to the related sciences (physics, geology etc.) and thus, there is little ability to predict these impacts in spite of the much advertised advances in technology. Whatever predictions are done are limited to 50 to 100 years. In fact the planned life of these dams is about 100 years ! On the other hand it appears that in the engineering that resulted in the Anangpur dam, assessing the impact of the dam on the local/global ecosystem and over a long period of time was intrinsic to the design cycle. Secondly, in spite of the inputs of the 'poor' technology that existed then, it appears that there was the ability to forsee possible disasters and thus avoid them.

Seen in this light one cannot dismiss the Anangpur dam as just a relic of the past with no relevance today. Nor can one argue that the Anangpur dam is a very small dam and therefore comparison with the Sardar Sarovar Project is not fair. We have shown quite clearly that the flaws with the SSP are at a very basic level and that the design rules that form the basis of the SSP would result in a bad engineering solution whether they are used to design a large dam or a small dam. What is involved is a change in perspective and attitude and not a change in size. By change in attitude we mean a change within the profession - within engineering and not in our personal lives outside it.

Future work on this project can take two possible directions. One would be to study the Anangpur dam ( and possibly a couple of others) and try and deduce the general design rules that could have resulted in such a solution. In other words deduce the general from the particular. The other, probably less difficult, route would be to study the traditional texts on civil structures and water management and recast them in modern parlance. The chief difficulty in the second approach would be to obtain translations and to bridge lapses in translation.

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## DEDICATION

One of us (Srinivas V. Veeravalli) wishes to dedicate this paper to the memory of Prof. K.J. Shah. Through numerous discussions Prof. Shah forced us to examine the fundamental presuppositions of modern science and engineering and also appreciate their limitations. The discussion did not stop with a simple criticism of modern science but also pointed to the direction in which a solution could be sought albeit in a different understanding of science and in a different tradition. His life and work inspired this project (specifically he sensitized us to the problem of 'side-effects') and continue to serve as a source of inspiration.

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## *Appendix*

A brief outline of the modern design procedure for dams (taken from Modi, 1988).

### (i) Investigations for reservoir planning

The following three types of investigations are required:

(a) *Engineering Surveys:* The area of the dam site, reservoir and other associated work is surveyed and a contoured plan of the entire area is planned. From the contoured plan the storage capacity and the water spread area of the reservoir at various elevations are determined.

(b) *Geological Investigations:* Geological investigations are required to determine the suitability of foundation for the dam and watertightness of reservoir basin.

(c) *Hydrological Investigations :* These include study of runoff pattern of river at the proposed dam site to determine the storage capacity of the reservoir corresponding to a given 'demand', and determination of hydrograph of the worst flood to determine the spillway capacity and design.

### (ii) Criteria for selection of site for a reservoir

The selection of site depends on the following factors:

(a) Suitable dam site must be available near proposed reservoir.

(b) The river valley at the site should be narrow so that the length of the dam to be constructed is less and it should open out on the upstream side to provide a large basin for the reservoir.

(c) The surrounding hills constituting the rim should be water tight.

(d) The reservoir basin should be reasonably water tight so that stored water is not able to escape under the surrounding hills.

(e) Minimum land and property is submerged in reservoir.

(f) The site should be such that it avoid water from those tributaries which carry unusually high content of sediment.

(g) The site should be such that adequate reservoir capacity is made available.

(h) As far as possible a deep reservoir must be formed so that the land cost per unit of capacity is low, evaporation loss is less and there is less likelihood of weed growth.

(i) The reservoir site should be such that there are no objectionable minerals and salts present in soil and rocks at the site.

(j) The quality of water stored in the reservoir must be satisfactory for its intended use.

(k) Cost of associated works such as roads, rails, housing colonies for workers and other staff etc. are not excessive.

**(iii) Control of sedimentation of reservoir**

(a) *Selection of site:* Select a site into which sediment flow is minimum.

(b) *Reservoir design:* Solutions like increasing reservoir capacity in stages, providing outlets.

(c) *Control of Sediment flow :* By check dams and vegetation screens.

(d) *Removal of sediment Deposits:* By excavations or scouring through slices.

(e) *Erosion control in Catchment Area:* By various methods of soil concervation like afforestation, control of deforestation, re-grassing, control of grazing etc.,

**(iv) Factors Governing type of Dam**

(a) *Topography:* The shape of valley considerations.

(b) *Geology and Foundation Conditions:* Geological characters an thickness of strata, their inclination/permeability and relation to underlying strata existing fault and forces.

(c) Availability of Construction Material: Availability in sufficient quantity near site.

(d) Spillway size or location.

(e) Environmental Considerations.

(f) Earthquake Zone.

(g) *Cost:* Of construction and maintenance.

(h) General Considerations: Considerations such as problem of diverting the stream flow during construction, availability of labour and equipment, accessibility of sites, limitations of outlet works and cost of protection from spillway discharges.

**(v) Selection of Site for a Dam**

(a) Suitable foundations.

(b) Economical considerations: Length of dam as small as possible and for a given height it should store large volume of water, river valley at the dam site should be as narrow as possible.

(c) As far as possible the dam should be located on high ground as compared to river basin.

Other considerations which go into selection of a dam site have been covered in reservoir planning.

**(vi) The actual process of designing dam**

(a) *Reconnaissance:* Visiting various sites and gathering information which will be useful for planning the detailed surveys.

(b) *Preliminary Investigations:* Getting sufficiently corrected data at various sites selected during reconnaissance, to start planning on most promising site.

(c) *Final Investigations:* Preparation of site surveys, preparation of topographical maps, geological studies, determination of type of dam to be studied, planning foundation treatment, rehabilitation planning, relocation of adjacent structures planning, estimates of cost, determination of final location of dam, construction equipment, colonies for labour.

* * *