# Engineering News

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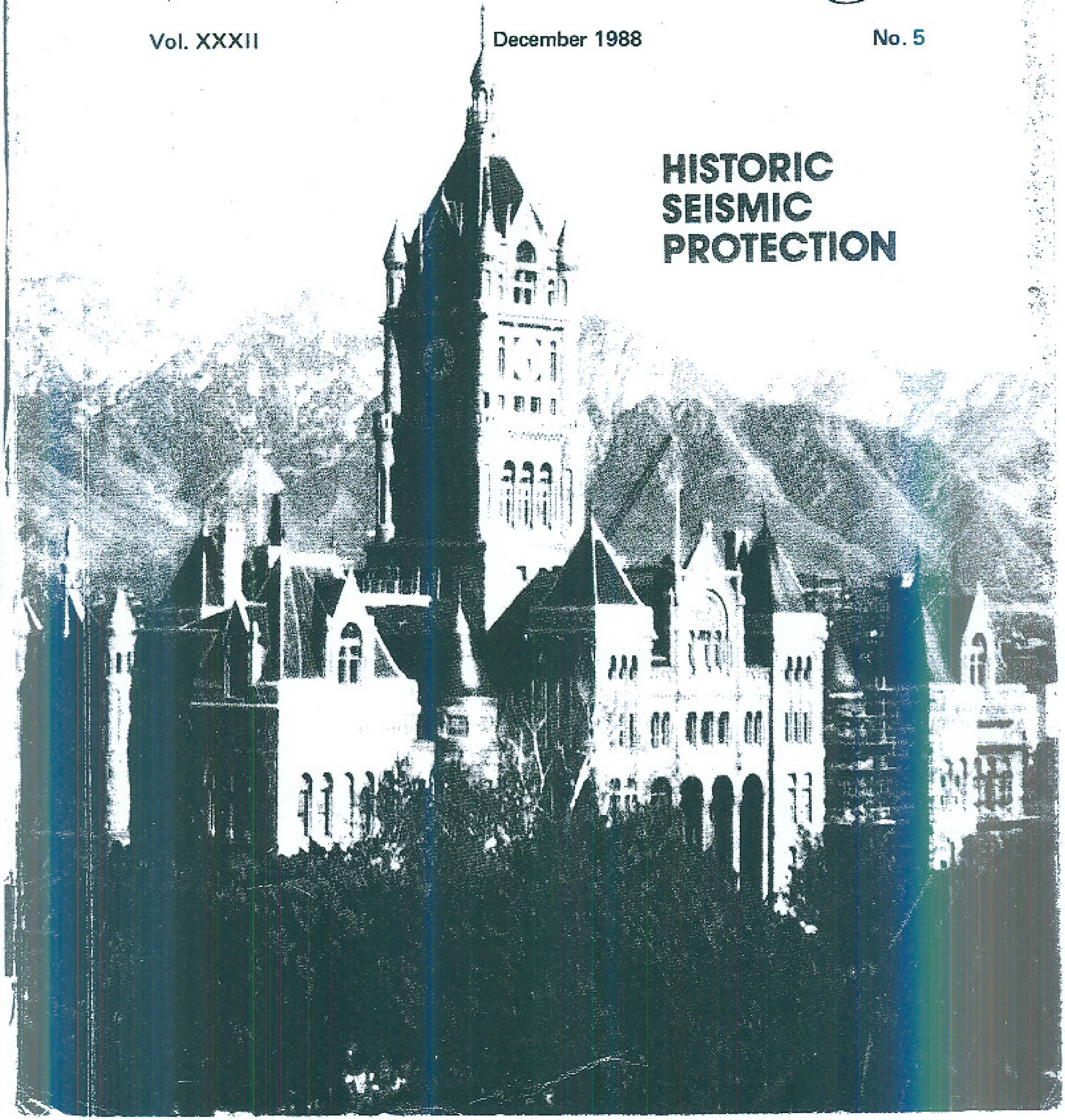
## HISTORIC SEISMIC PROTECTION



# CODE OF ETHICS

## PAKISTAN ENGINEERING CONGRESS

بسم الله الرحمن الرحيم

*In the name of God, the Beneficent, the Merciful*

WHEREAS Allah enjoineth upon his men to faithfully observe their trusts and their covenants ;

that the practice and profession of engineering is a sacred trust entrusted to those whom Nature in its magnificent bounty has endowed with this skill and knowledge ;

that every member of the profession shall appreciate and shall have knowledge as to what constitutes this trust and covenant, and

that a set of dynamic principles derived from the Holy Quran shall guide his conduct in applying his knowledge for the benefit of society.

Now, therefore, the following Code of Ethics is promulgated. It shall be incumbent upon the members of the West Pakistan Engineering Congress to subscribe to it individually and collectively to uphold the honour and dignity of the engineering profession :

١- إِنَّ اللَّهَ يَأْمُرُكُمْ أَنْ تُؤَدُّوا الْأَمَانَاتِ إِلَىٰ أَهْلِهَا وَإِذَا حَكَمْتُمْ بَيْنَ النَّاسِ أَنْ تَحْكُمُوا بِالْعَدْلِ ۚ إِنَّ اللَّهَ نِعِمَّا يَعِظُكُمْ بِهِ

"Allah commands you to render back your trusts to those to whom they are due, and that when you judge between people, you judge with justice. Allah admonishes you with what is excellent". iv : 58

1. You shall be honest, faithful and just, and shall not act in any manner derogatory to the honour, integrity or dignity of the engineering profession.

٢- أَوْفُوا الْمِكْيَالَ وَالْمِيزَانَ بِالْقِسْطِ وَلَا تَبْخَسُوا النَّاسَ أَشْيَاءَهُمْ وَلَا تَعْثَوْا فِي الْأَرْضِ مُفْسِدِينَ ○

"Give full measure and weight justly and defraud not men of their things, and act not corruptly in the land making mischief". xi : 85

2. You shall use your knowledge and skill of engineering for human welfare, and render professional service and advice which reflects your best professional judgment.

٣- وَلَا يَجْرِمَنَّكُمْ شَنَآنُ قَوْمٍ عَلَىٰ أَلَّا تَعْدِلُوا ۚ اعْدِلُوا هُوَ أَقْرَبُ لِلتَّقْوَىٰ

"And let not hatred of a people incite you not to act equitably. Be just ; that is nearer to observance of duty". v : 8

3. You shall not injure maliciously, directly or indirectly, the reputation or employment of another Engineer, nor shall you fail to act equitably while performing professional duty.

٤- أَوْفُوا بِالْعُقُودِ ○

"Fulfil the obligations". v : 1

4. You shall faithfully observe and fulfil all your obligations.

٥- وَلَا تَأْكُلُوٓا أَمْوَالَكُم بَيْنَكُم بِٱلْبَٰطِلِ وَتُدْلُوا بِهَآ
إِلَى ٱلْحُكَّامِ لِتَأْكُلُوا فَرِيقًا مِّنْ أَمْوَٰلِ ٱلنَّاسِ
بِٱلْإِثْمِ وَأَنتُمْ تَعْلَمُونَ ۝

"And swallow not up your property among yourselves by false means, nor seek to gain access thereby to the judges, so that you may swallow up a part of the property of men wrongfully while you know". ii : 188

5. You shall not abuse your position or power, nor accept illegal gratification of any sort.

٦- وَقُولُوا قَوْلًا سَدِيدًا ۝

"And speak straight words." xxxiii : 70

6 You shall express your opinion on engineering or other matters in a frank, open and straightforward manner.

٧- اجْتَنِبُوا كَثِيرًا مِّنَ الظَّنِّ إِنَّ بَعْضَ الظَّنِّ إِثْمٌ
وَلَا تَجَسَّسُوا وَلَا يَغْتَب بَّعْضُكُم بَعْضًا

"Avoid most of suspicion for surely suspicion in some cases is sin; and spy not nor let some of you backbite others". xlix : 12

7. You shall not criticise another engineer's work without his knowledge, nor malign or injure his professional reputation.

٨- وَلَا تَقْفُ مَا لَيْسَ لَكَ بِهِ عِلْمٌ إِنَّ السَّمْعَ
وَالْبَصَرَ وَالْفُؤَادَ كُلُّ أُولَٰئِكَ كَانَ عَنْهُ
مَسْئُولًا ۝

"And follow not that of which thou hast no knowledge. Surely the hearing and the sight and the heart, of all these it will be asked." xvii : 36

8. Your professional advice shall be based on full knowledge of the facts and honest conviction, and you shall not write articles or advertise in self-laudatory language or in any manner derogatory to the dignity of the profession.

٩- وَتَعَاوَنُوا عَلَى الْبِرِّ وَالتَّقْوَىٰ وَلَا تَعَاوَنُوا
عَلَى الْإِثْمِ وَالْعُدْوَانِ وَاتَّقُوا اللَّهَ

"And help one another in righteousness and piety, and help not one another in sin and aggression and keep your duty to God." v : 2

9. You shall help one another in upholding and doing what is right, and shall not associate with those who transgress and those who indulge in unethical practices.

١٠- وَأَمْرُهُمْ شُورَىٰ بَيْنَهُمْ

"And whose affairs are decided by counsel among themselves." xlii : 38

10. You shall decide matters of common professional interest by mutual consultation.

١١- وَاعْتَصِمُوا بِحَبْلِ اللَّهِ جَمِيعًا وَلَا تَفَرَّقُوا

"And hold fast by the covenant of God all together and be not disunited." iii : 102

11. You shall strive individually and collectively to enhance the prestige of the engineering profession by ordering your conduct in accordance with this Code of Ethics, and shall not be disunited.

# EDITORIAL

## DEVASTATION BY FLOODS
## and
## NEED FOR NEW STRATEGIES FOR MITIGATION

The unprecedented floods of October, 1988 in the Sutlej and Ravi Rivers claimed a big toll of human lives and inflicted losses worth billions of rupees to movable and immovable properties and standing crops. There has been a lot of clamouring that people were taken unaware in the absence of timely warning by the Irrigation & Civil authorities and they could not move to places of safety. There were also repeated news that to save certain headworks the authorities had to cut the right or left marginal bunds at various places. Lacs or thousands of cusecs of water passing through such artificial cuts in the safety bunds inundated lacs of acres of cultivated lands and ruined hundreds of villages in their wake.

Some of the major causes of floods are:

— The natural hydrological cycles in the catchment of various rivers bring in variable quantum of flows in different years. From the hydrological investigations and computations it is possible to estimate the recurrence intervals of floods of various magnitudes. For instance the magnitude of the floods of 25-year, 50-year, 75-year or 100-year recurrence intervals can be estimated. Unfortunately, so far, it is not possible to know the exact time or period when a flood of particular recurrence interval can be expected. For instance a flood of 50-year recurrence interval may occur on the third, fourth or any year. There are dry or wet cycles in every stream. During dry spells people habitate the banks and even the dry beds of rivers and when the wet cycle takes its turn and causes lot of damage, people call it an unprecedented flood- since human memory is very shotlived.

— Before the spread of civilization the rivers were like wild animals, free to move in any direction at their discretions. Floods would come, spill the adjoining land and with their iressioni water coulc easily drain back into the rivers. The silt carried by the flood waters was uniformly spread with the country-side thus increasing its fertility. However, with the gradual development of Towns and Cities, Construction of Headworks, Barrages and Canals for the Irrigation of virgin lands, embankments hac to be constructed along the river banks which restricted the river flow within the Laveed Course. This resulted in deposition of the part sediment load, carried by floods, within the river bed and consequent gradual accretion of bed levels and flood heights. This necessitated perpetual raising of flood embankments and connected structures. Development of social amenities like roads, canals and railways necessitated building of embankments above the natural surface and thus interrupted the natural drainage of flood and rain waters.

— After the implementation of 'Indus Waters Treaty of 1960' the waters of three eastern rivers namely, the Sutlej, the Beas and the Ravi were allocated to India while the three western rivers - namely the Chenab, the Jhelum and the Indus came to the share of Pakistan. The three Indian rivers were particularly diverted, abvoe the Indo-Pak border, by construction of dams or building new Irrigation Canals. So, practically no flow was left in these rivers below Indo-Pak border. The regular and flood flows in the eastern rivers used to flush and clean their normal active sections/ creeks. With the attenuation or elimination of flows the river beds started deteriorating with wild growth of jungle and encroachments by local population in the form of crop cultivation and habitations. Sometimes people build embankments across the river bed to cross their water courses and roads etc. All such obstructions and blockades result in heavy spilling beyond the river bank whenever flows of even normal magnitudes are encountered. Dams built in the three Indian rivers have provided spillways big enough to cater for the maximum possible floods to be experienced at their sites. So during the eventualities when the dams are full upto their maximum capacities and the highest flood if experienced the spillways are opened to save the dam. Such water, while flowing down into Pakistan through the deteriorated beds of river naturally play havoc with the human lives and properties in such Doabs even if a timely warning is received because the people cannot imagine the magnitude of such a flood.

With the allocation of three rivers to India the Irrigation Canals historically fed by Sutlej and Ravi rivers had to be transferred to alternative sources by construction of replacement works like two Dams at Tarbela and Magla; five barrages at Chashma, Rasul, Marala, Qadirabad. Sidhnai & Mailsi; and eight link canals namely- Rasul-Qadirabad, Qadirabad-Balloki, Balloki-Suleimanki, Trimmu-Sidhnai, Sidhnai-Mailsi, Mailsi-Bahawal, Chashma-Jhelum & Taunsa-Punjnad. Building Dams & Barrages on the three western rivers decreased the historic magnitude floods/flows in their old courses resulting in deterioration in the channels and decrease in their flood passing capacities. Similarly in the three eastern rivers, lack of normal flows and encroachments in their waterways resulted in deteriorations. This causes the occasional floods to spill beyond their normal banks.

- During construction of replacement works some of the link canals had to be thrown into almost dry ponds of certain barrages. For instance, Qadirabad-Balloki link falling upstream Balloki Barrage with practically no water of Ravi river, Balloki-Suleimanki Link falling in the dry pond of Suleimanki Barrage and Taunsa-Panjnad link droping its flows in the empty pond of Panjnad-Headworks, resulted in heavy shoal (bela) formation within the ponds. These belas created within the waterways of barrages in turn decreased the flood-passing capacities of such structures and this required cutting of the marginal bunds to save these costly structures. Traditionally, the belas formed in the ponds of barrages used to be washed down by operation of gates but now, especially in the eastern rivers, there is not enough water to flush down the belas that are progressively increasing at their sites. Their structural stability is as such threatened by negative growth on them.

- Some of the historic flood passages have been notified by the Federal Flood Commission on the basis of past experience and construction of permanent structures along such courses has been banned to allow unobstructed flows of flood waters. For instance, the flood route on the right bank of Ravi river has been notified as a draiange area but unfortunately big Industrial Complexes have been built on the G.T. Road near Kala Shah Kaku and all along Lahore-Sheikhupura Road. Some of the factories are located right in front of the flood openings built in the G.T. Road and the Railway line. Obviously such obstructions in the path of floods cause direct damage to themselves and indirect damage to the adjoining properties.

- The topic of floods-their causes, effects and methods for their mitigation is very exhaustive and cannot be fully dwelt upon within a short editorial. The main idea however, is to give some food for thought to the people at the helm of affairs in the Irrigation and Power Departments, the Federal Food Commission and the concerned Civil authorities to evolve new strategies for mitigation of floods and to obviate collosal damages to precious Irrigation structure and avoidable losses of lives and properties.

Some of the methods suggested for alleviating the miseries of floods are discussed hereunder:-

The design flood-passing capacity of all the barrages & major bridges on the rivers must be ensured even by keeping floating dredgers on all the headworks or by physical excavation during dry periods. The waterways between the main guide bunds of the headworks must be kept clear of deposited sediments and wild jungle growth. This would obviate cutting of marginal bunds to save the structures. Expenditure on such works will be off-set by saving of losses to life and property inflicted after cutting the marginal bunds. Barrages are the life-line of the nation and have to be saved at any cost. Sometimes the shoal-formation upstream of the barrage results in high concentration of flows in some parts of the barrage which results in irrepairable loss to the structure and poses a serious threat to the restoration of canal supplies to the perennial canals supporting millions of people. In case the design capacity of the structure is lesser than the expected floods then suitable breaching sections should be provided to byepass only the surplus floods. However, in such cases the routes of flood waters should be carefully delineated and notified to the general public for avoiding building of permanent habitations along such passages. Arrangements should also be made for public alarms and quick information system in such areas to give timely warning to the affected people to shift to notified safe places.



Contd. P-97

# MASSIVE RESISTANCE

*by*

*James S. Bailey* *
*Edmund W. Allen* **

Unlike the world renowned mechanical figures that have promenaded hourly atop clocktower since 1352, the statues adorning Salt Lake City's historic clocktower were never meant to move. Thus when they shifted on their pedestals during a 1934 earthquake, just 40 years after the 250 ft high tower was completed, city officials quickly removed them to prevent potential injury to passersby below.

As a result of continuing seismic damage since then to the landmark tower and the five-storey stone masonry building out of which it rises, the city now is in the midst of a massive rehabilitation effort to reinforce them against future shock. The Salt Lake City and Country Building, as it is called, is believed to be the first historic structure in the world to be retrofitted against possible seismic damage using base isolation.

Key elements in the scheme are 447 specially designed base isolators installed between the structure and its original massive concrete footings. A new concrete structural system (built under the building's masonry walls, its eight cast-iron columns and the clocktower's massive sandstone piers) distributes the structure' loads to the isolators.

The sandwich-like insulators, supplied by Dynamic Isolation Systems, Berkeley, Calif., consist of alternating layers of bonded metal and rubber. They are very stiff in the vertical direction to transfer gravity loads, but are flexible in the horizontal direction to isolate the building from horizontal components of seismic forces. The isolators under exterior walls are fitted with lead cores that act as fuses to prevent building motion due to high winds, but yield and provide inelastic viscous damping to absorb earthquake energy during a seismic jolt, which in turn helps control horizontal deflections.

Additionally, a reinforced concrete retaining wall provides a 12 in, seismic gap around the building's perimeter, thus permitting the building to move relative to the surrounding ground.

The structural load-transfer system under the building consists of an elaborate system of concrete beams and a steel grillage that distributes building loads through the isolators to the

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**Founder & President, E.W. Allen & Associates.

foundations:

o Concrete side beams cast on either side of all masonry walls, and set 4 in. into each wall, support the masonry between isolators. Post tensioning rods, drilled through the beams and walls, are stressed to clamp the masonry material tightly between the new beams.

o Concrete cross beams cast on top of the isolators connect paired side beams, and act as double cantilevers in transferring the wall load from the side beams onto the isolators. At isolator locations, masonry wall material is removed to accommodate isolator and cross beam height.

o A steel grillage installed beneath the isolators distributes the vertical loads evenly from isolators to the existing footing. Small wide-flange beams are welded together to form the grillage system.

o A concrete floor cast above the load-transfer grid acts as a rigid diaphragm connecting all side beams and linking all the isolators so they act in unison as a system.

For the isolators to work properly, the structure's foundation walls also had to be isolated from the ground horizontally. The moat around the building and tower permits the building to move horizontally, relative to the ground. Computer simulation analysis indicated that the maximum horizontal deflection the building should experience during the design earthquake is about 5 in. Thus the seismic gap's addtional 7 in. clearance provides a factor of safety in the extremely rare event that an earthquake larger than the design one should occur. A bumper restraint system to lessen the possibility of isolation instability will be installed in the moat as an extra safety device.

In addtion to isolating the building and tower from their foundations and the surrounding ground, the seismic retrofitting scheme also involved strengthening the two structures internally, including:

o Building a structural steel space truss within the clocktower to stabilize it and transfer seismic forces down into the main building.

o Installing structural plywood diaphragms in the fifth floor attic spaces to stabilize the top of the building's exterior masonry walls.

o Erecting structural plywood shear walls within attic spaces, directly above existing interior masonry walls, to laterally stabilize the main building's roof structure.

o Anchoring exterior masonry walls to the floor and attic diaphragms.

o Anchoring diaphragms to interior masonry walls for shear and to provide a tension tie through the walls.

o Adding a reinforced, lightweight

concrete topping on existing floor diaphragms to increase their stiffness and strength.

o Anchoring all exterior seismic hazards, such as chimneys, statues, dormers, balustrades, parapets and cornices.

## AS–BUILT CHALLENGE

From the very start of the project, as–built conditions proved to be a continuing challenge to both design and construction of retrofitting. A set of drawings of the original structure, obtained from an architectural firm in Iowa, showed totally noncombustible masonry and steel construction for the entire building. Actually, however, the original fourth and fifth floors, attic, roof and tower interior construction as well as the first floor, which was built at a later date, were all framed in wood. And there was a noticeable difference in brick mortar quality at the fourth level also, which showed up in inplace shear tests. Furthermore, during excavation it was discovered that footings beneath the building were roughly twice as large as shown on the original plans–thus necessitating a major design change.

Because the original building construction went considerably over budget, a new general contractor was probably brought in when construction was between the third and fouth floors. And because masonry work varied considerably throughout, it's possible that a new masonry contractor also was brought in.

The final plan for reinforcing the building and its tower evolved from a number of studies that various design consultants had conducted for the city and country since the early 1970s (see sidebar). The consultants recommended strongly that the structures be saved, primarily because of their historical significance and unique architecture. But while the studies indicated that the building and tower for the most part were structurally sound and capable of meeting all requirements of the 1940 Uniform Building Code without modification, seismically they were woefully inadequate. Bringing them up to current seismic codes required extensive modification.

The primary challenge facing the design team in the preliminary phase was to refine the initial structural study and explore ways of reducing the antici–pated cost of seismic retrofit. Three approaches were considered: UBC, ABK and Base Isolation.

UBC proved to be the costliest and architecturally most destructive of the methods. It would have required total gutting of the interior and building a new structure within the original exterior ornamental facade. The ABK method although least expensive of the three, nevertheless was also architectu–rally unsuitable, since it called for shotcreting all or most of the interior brick walls.

The Base Isolation solution cost more than £1 million over the ABK method. But it was considerably less expensive than the UBC approach– and architecturally the least disruptive of alternatives. Additionally, computer analysis indicated that a base–isolated building would stay well within the elastic range (0.08G vs 0.55G for a nonisolated building), thus predicted damaged would be minimized for the earthquake design.

Despite the fact that no seismographic records for major earthquakes in the Salt Lake area exist, earthquake records in other areas, having characteristics similar to those that might be expected in Salt Lake City, indicated that the building could possibly be subjected to amplified force levels as high as 0.55G. While approaches such as the UBC and ABK methodologies would have prevented building collapse, non–catastrophic damage would still be extensive due to seismic energy being absorbed through inelastic deformation of building components.

Using base isolators, on the other hand, shifts the fundamental period of vibration of the structure to a range outside of the predominant energy content of the design earthquake. The structure thus would tend to vibrate at a different frequency than the ground below it, and thereby avoid resonance and significantly reduce the level of force experienced by the building. (Base isolators work in a way similar to shock absorbers in an automobile that isolate the occupant from road vibrations.).

## ON–SITE CHANGES

The original base isolation plan anticipated installing a spread footing foundation system, complete with isolators and tie struts– beneath existing footings. But exploratory trenches dug around the foundation revealed significant variance between the original drawings and as–built conditions. Footings beneath the building turned out to be roughly 50% wider and thicker than shown on the original plans: and a massive concrete mat, 75 ft square by 4.5 ft thick, underlay the four main tower piers. These findings made it virtually impossible to proceed with the original concept.

So the design team reconsidered the method of installation and came up instead with the concept of mounting the isolation system on top of the existing piers. This, in turn, required replacing the existing floor with one that is 1 ft 2 in. higher to provide sufficient clearance for the isolators and load–carrying system.

Although the new approach eliminated a significant amount of tunneling and undermining work, hundreds of slots had to be cut through the existing walls to install the isolators. And

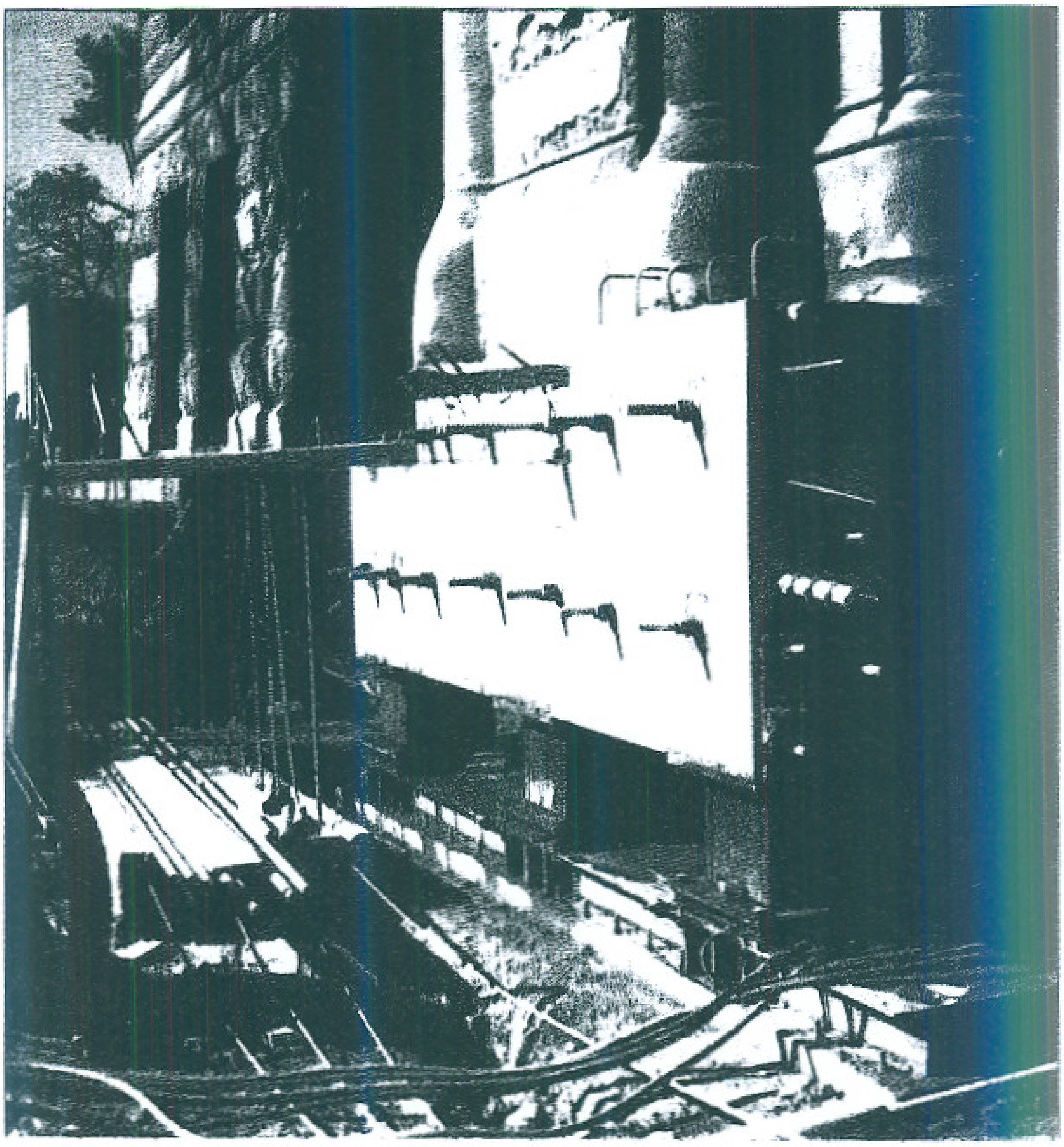
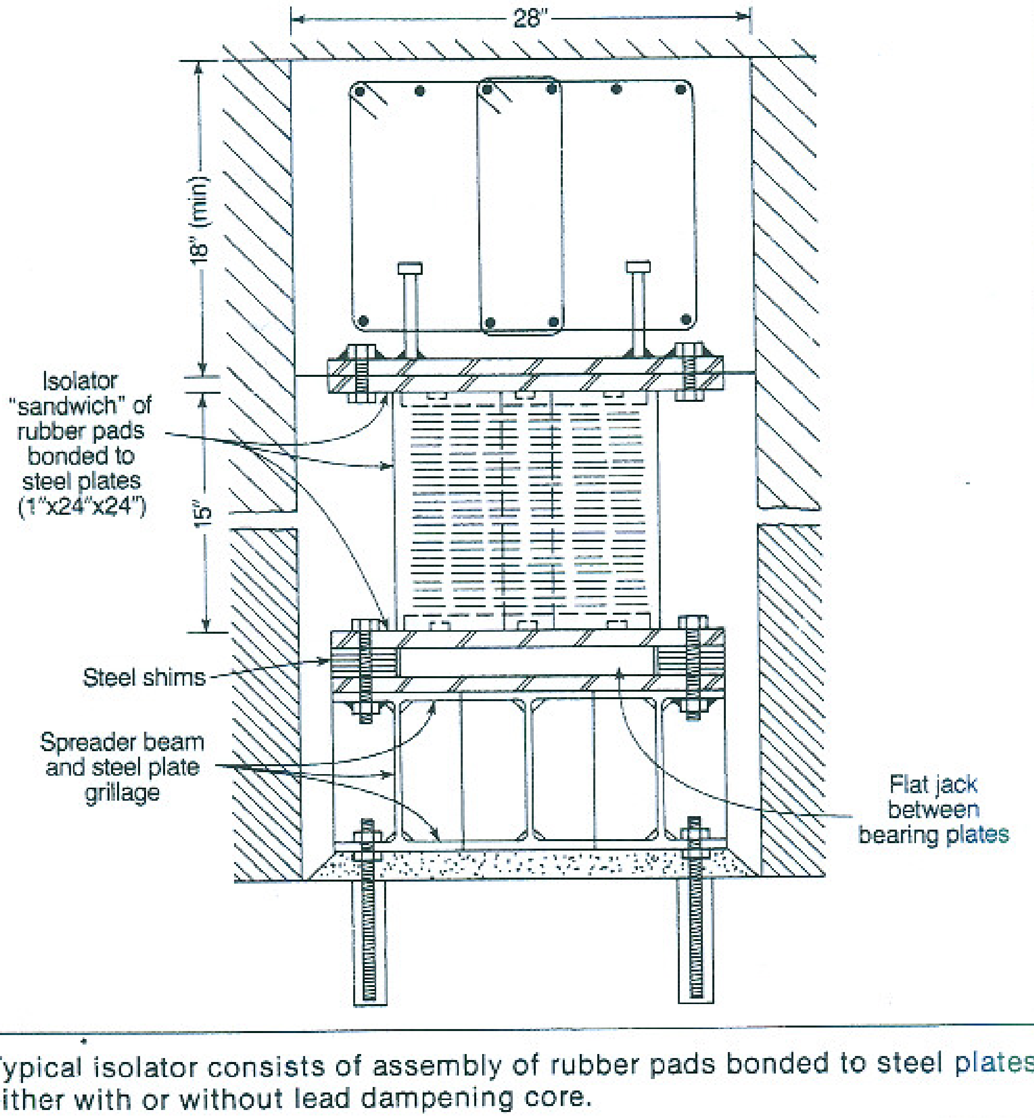


FIGURE 1
## BASE ISOLATOR




Typical isolator consists of assembly of rubber pads bonded to steel plates, either with or without lead dampening core.

construction of the side beams required a considerable amount of notching into existing walls. Tests indicated that stonework at the base of existing walls was extremely hard (over 21,000 psi compressive strength), which would make it exremely difficult to cut even using impact hammers. The sand-lime mortar, on the other hand appeared to be of extremely poor quality at many locations. This ruled out any use of impact hammers to remove the stonework, because they would vibrate much of the mortar loose. Thus, only nonimpact tools were specified for removing stone.

Prior to bidding this portion of the job, prospective contractors tried a number of different methods to determine the most efficient means of removing stonework using nonimpact tools. Two methods, line drilling (drilling a line of closely spaced holes to form the cut) and high pressure water jet cutting, worked satisfactorily, but neither proved to be cost effective.

The successful contractor, Jacobsen Construction Co., Salt Lake City, came up with an alternative method that used a specially designed wire saw for removing a large portion of the stone cutting. Manufactured in Spain, the saw consists of a ½ in. dia. diamondstudded steel wire, guided by a series of pulleys that are adjusted to various cutting situations. To make vertical cuts, the contractor used large diamond blade rotary saws, upto 4 in. in diameter.

Every effort was made, in preparing bid documents, to have the contractor take into account in the bid any minor variations in existing footing elevations. A difference of plus or minus 3 in. from the average elevation shown on the drawings was to be accounted for by adjusting grout thickness, cross beam depth, and so forth. Preliminary data indicated that the 3 in. tolerance would be adequate.

Upon removal of the first floor, however, it became apparent that almost the entire south half of the building foundation was up to 6 in. higher than shown on the bid documents. The north half, where footing elevation measurements had been taken previously, was almost entirely at the assumed elevation. And, while the original drawings showed uniform thicknesses and widths for plinths, the stone actually varied greatly in thickness, both along the length, and from side to side.

The variable footing elevations, however, turned out to be a relatively minor problem when compared to variations in plinth elevations. Using plinth thicknesses shown on the original drawings, the isolation system was detailed so that the mortar joint to be removed at the top of the uppermost plinth, occurred at the isolator's mid-height. Providing 6 in. clearance between the edge of the slot and the isolator would then permit 12 in. relative movement between top and bottom of isolator before interference could occur.

As it turned out, points higher than anticipated required the removal of additonal plinth material to allow the 12 in. movement, and lower joints required blocking out of the side beams. To accommodate the shallower depth caused by the high plinths, side beams had to be redesigned during construction. And at all locations where plinths were extremely high, the upper-most plinth was trimmed along with the notch and captured by the side beams. The beams were cast in place down to the mortar joint between plinths.

Installing the isolators under the building's cast-iron floor support columns posed a special problem. The, load on each column had to be picked up so that the bottom of the column and its cast iron base plate could be cut off, removed and replaced with an isolator. The solution: a structural steel column clamping device was designed and fabricated to grip the column in friction as well as bolt double-shear. The clamp, in turn, was bolted to steel channels that served as needle beams for jacking against to pick up the load. An additional collar was installed below the clamping collar to support the new first floor beams.

Another major concern was building settlement and potential cracking at time of mortar joint removal at the base of the walls-the last step in the isolation scheme. To overcome this problem, the isolators were pre-loaded, using Freyssinet flat jacks, to take up any slack before cutting the mortar joints between the isolators.

The base isolator approach to seismic protection offers the possibility of preserving as much of a building's original architectural fabric as possible, while at the same time providing a greater degree of protection from nonstructural earthquake damage than conventional strengthening methods. To be economically retrofitted with this system, however, a building must substantially meet such criteria as a reasonably regular shape, with height less than width, to elimintate uplift: a site that allows the building to move relative to the ground without interference from adjacent structures: interiors worth preserving: and a configuration where repair to nonstructural damage for a building in an unisolated condition is likely to be considerably more difficult or costly than when it is isolated.

(Courtesy: 'Civil Engineering' Magazine (Sep. 1988). of American Society of Civil Engineering, U.S.A.)

# SELECTION OF SCHEMES FOR REHABILITATION.

*By*

*Mian Sikander Hayat**

## 1. IRRIGATION IN PAKISTAN.

### 1.1 HISTORY

Pakistan is situated in an arid zone. The country has a total land area of about 80 million hactares of which 40% or about 31.5 Million hactares are suitable for crops, range and forest production. A major portion of the country's irrigation depends on the flow in its rivers forming tributaries of River Indus. Maximum temperature in the Indus plain goes upto 49$^{O}$c in May and June. Annual precipitation is less than 20 mm in most of the area of the plain. Pan evaporation may exceed 1.5 meter in a year. Heavy rainfall does occur during monsoon season (July to Sep) causing substantial flood damages. Indus Basin is one of the world's most fertile, basins and is thickly populated and surrounded by high mountains from northern, northeastern and western sides. On southern side the basin boundary goes upto the Arabian Sea. These mountains have high peaks, which remain covered with snow throughout the year. These high peaks with vast deposit of snow and capacity to block and capture monsoon winds make them to disgorge their load in the form of snow and rainfall. Most characteritic features of these mountains are their soaring heights, snow capped and steep-sided rugged peaks, valley glaciers and topography deeply cut by erosion. The snow fields feed the valley glaciers which consitute the sources of most of the rivers. Indus river has five major tributaries besides numerous storm-water channels. The annual run off of the river Indus and its tributaries is 168 m.a.f (Million acre feet). Like other great ancient civilizations in the aird zones as of Nile the Indus valley civilization is known as Hydraulic civilization. In upper reaches of the catchment the bed slope is very steep with the result that freshets pick up huge quantity of organic debris and deposit the same at the foot of the hills.

The bed of the rivers in the plains is composed of alluvial soil which gets scoured and the sediments form suspended load getting deposited mostly in the bed of the irrigation channels where the velocity decreases. The average slope of the land in the Indus plain towards sea is 1 meter per kilometer in the northern fringe reducing it to 0.25 meter per kilometer near the sea. This gradual slope provides a great

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potential for flow irrigation. The rainfall in the basin is depicted in Fig (1).

In ancient days much before the advent of irrigation by flow the habitation used to be along the banks of the river where the ground water was at a shallow depth and fit for irrigation. The farmers developed persian-wheeled well driven by bullocks (Fig. 2) and lifted the ground water. The people took advantage of the river spill as well.

The rivers provided line of communication also. With the increase in population the need for food and fibre also went-up. The farmers blocked the water in the non-perennial streams and started irrigating their fields. The first regular diversion work in the Sub Continent was constructed on the rivers of South India with monsoonal character. Being encouraged with this invention the ancient engineers, almost a thousand years ago, succeeded later on to divert perennial flow. The earliest irrigation canal in the sub continent was the Western Jamna Canal first constructed in the 14th Century. Due to some reasons it was abandoned but again restored in the 15th Century. After being put off once more it was reactivated in 1820. In those days the diversion works used to be by building temporary dams consiting of shingle and brush wood. These dams were generally washed away during floods and were rebuilt during winter to make the supply available for winter crops. It was in 1870 when it was decided to control the river effectively with permanent structures (weirs) and make the supply in canals available, throughout the year. With this construction a new engineering chapter was opened to lay foundation of huge structures on permeable strata. With lot of encouragement and improved economy, quite a few weirs were constructed subsequently where big irrigation canals took off.

## 1.2 IRRIGATION SYSTEM

The canal irrigation system came into being more than hundred years ago and is considered to be the largest open-channel contiguous irrigation system in the world. It covers a gross area of 17.04 million hactares out of which 82% is culturable. It has 48 main canals taking off from 20 big river diversion structures. Many of the canals are even large by world standards, 15 of them having capacities of over 400 cubic meters per second. Cumulative operating capacity of these canals is 6,990 cubic meters per second. Their annual conveyance capacity is 220 billion cubic meters. These canals traverse about 63000 k.m. to command about 14 million hactares of culturable area through 87500 water courses (Farm Channels). There are 12 link canals transporting bulk water supply from Western to Eastern rivers and two large dams (Tarbela & Mangla) with storage capacity of 18.1 billion cubic meters which have been constructed recently.

In addition to this large canal system, there are more than 200,000 private tubewells each having an average capacity of 30 litres per second and over 12000 public tubewells with designed capacity of 60 to 120 litres per second. These tubewells have been installed for supplementing the canal supply at the source of the water course and to lower the water table which has increased because of intensive flood irrigation, seepage from earthern canals and inadequate stormwater drainage outlets. The tubewell water where-ever its salt contents permit is mixed up with the canal supply at the source of the water-course i.e. down-stream of the farm off take structures (outlets) and the mixed water is used for irrigation. The average capacity of the water course is between 56 to 85 litres per sec. depending upon the area it has to irrigate. Because of scarcity of supply the water is delivered almost 40 to 75% of the culturable commanded area depending upon its availability in the canal. The farm holding on each outlet/ water-course ranges between 80 to 165 hactares.

The irrigation supply is based on the run-off in the rivers. With the construction of two big reservoirs (Tarbela & Mangla) the supply has been ensured to some extent but not 100%. Canals, in some areas, have to be operated on rotational basis at the time of short supply in the rivers. Due to occasional switching off and on of the canals, the silt laden water deteriorates the regime of the channels (details would be discussed in the later paragraphs).

The main and branch canals are provided with controlled structures where the supply could be regulated. The off taking structures of smaller channels including that of farm channels have been designed to draw water proportionate to supply in the canal/ and to share excess and deficient supply in the parent channel. The outlets usually share the silt laden water proportional to the area of their holding within water course command in which these are entitled to take the whole flow in the water course in turn. A seven day rotational period is usually fixed. Water supply to the canal system is governed in most areas by the supply available in the river system, rather than by actual crop-water requirement.

## 2.0 POOR PERFORMANCE AND ITS CAUSES

The irrigation system in Pakistan alongwith its excellent irrigation skill and master structures has inherent deficiencies which need to be removed to bring its out-put at par with the world's most efficient irrigation systems. Some of these are explained below:-

### 2.1 CONSTANT FLOW

The outlets are designed to deliver a fixed discharge in case the parent channel runs with its authorised full supply. The fixed discharge is not in accordance with the consumptive use of a crop which varies with its growth stage. Such demand is minimum at the earlier growth stage, maximum at the flowering/ seed formation stage and dwindles down as the crop comes to maturity. Fixed-discharge application of water is non-scientific. No allowance is either kept for the type of the soil to be irrigated. Moreover water application to the areas with higher water table/ and higher levels should vary but in actual practice it does not. The other factors affecting the balancing up of the equation are also ignored. Such constant flows may result in over-irrigation at one stage and under-irrigation at the other. Over irrigation supplements the ground water which some cases rises upto root zone of the crops and affects the yield. Under irrigation would cause soil moisture stress and ultimately reduces the crop yield.

## 2.2 LIMITED SUPPLY IN THE SYSTEM

The water is not adequate and is supplied to 40 to 75% of the area. With the construction of two big reservoirs, the supply position could be improved during period of July to September but the limited physical capacity of the system in most of the areas is a big constraint.

## 2.3 EXCESSIVE LOSSES OF IRRIGATION WATER

Irrigation system upstream of the outlets right from the diversion work in the river (Weir / Barrage), main canals branches, distributaries and minors is operated and maintained by the Government. The maintenance of the water courses (farm-channels) down-stream of the outlets is the responsibility of the farmers. A huge quantity of water is seeped into the soil and is lost. The research carried out jointly by the Mona Project and the Colorado State University in 1973 indicated that losses in the water courses are 40-45 percent. Later on field experiments were conducted by the engineers of the irrigation department and they proved that the losses due to seepage were not so high. One thing is beyond any doubt that the poor maintenance of the farm channels results in more evaporation, more leakages and loss in head of water as well. Interesting studies were carried out by different agencies in the past and their findings have been summarised as below:-

| | Agency | Losses in water cour-se % | Efficiencies | | |
|---|---|---|---|---|---|
| | | | Deli-very | Appli-cation | Irri-ga-tion |
| 1. | Lower Indus Project | 10 | 90 | - | - |
| 2. | Renelle Report | - | - | - | 85 |
| 3. | Harza | 10 | 90 | 75 | 68 |
| 4. | Tipton & Kam back | 10 | 90 | 78 | 70 |
| 5. | World Bank | 10 | 90 | 70 | 63 |
| 6. | Harza Report | 25 | 75 | 65 | 50 |
| 7. | Mona (13 water course) Wapda CSU (40 water course). | 44 | 56 | - | - |

Results of different studies vary which may be due to many reasons. Average irrigation efficiency is 67% meaning thereby that beside losing command, 33% of water is lost in transportation and application which is quite high. These losses could be reduced to a great extent if water courses are maintained properly. This could be achieved if responsibility of operation and maintenance is entrusted to some farmer's own established organization like Water Users Association and not to individual farmer as per existing practice. Such associations would inculcate a feeling amongst the water users that the water courses belong to them and proper maintenance would be in their own interest.

## 2.4 IRRIGATION METHODS

The age-old irrigation by flooding the fields needs to be changed with irrigation in furrows or even the surge application could also be tried and side by side the concept of farm drainage may also be considered where possible. Posibility of having sprinkler or drip irrigation could also be examined where gravity flow is not possible. However electric power supply could be a big constraint in such development.

## 2.5 LACK OF DRAINAGE FACILITIES

Huge quantity of water flowing on alluvial strata should have proper complementary drainage system to cater for the surface and sub surface water to keep the same out of the root zone. Absence of such system has proved detrimental to the agro-economic structure of the country and water table started rising at an enormous rate with the result that the ground water which used to be at a depth of 50 meters is now at places within the root zone. The problem was compounded by the construction of roads, railways, flood embankment and irrigation channels. The construction of big reservoirs and of the Link Canals further aggravated the situation. Although a big drainage net-work (both surface and sub surface) has been constructed in the country but extension of the same is very much necessary to check growing menace of water logging and salinity.

## 2.6 LIMITED CONTROL CAPACITY OF THE SYSTEM

As stated earlier the irrigation system in Pakistan was earlier based on run off in the rivers. At that time the available supply was only enough to cater for about 75% of the culturable commanded area. Later on with construction of storage reservoirs and installation of Tubewells the possibility of increasing the intensity is there but due to inadequacy in the structural capability of the irrigation channels it is not possible unless the channels are rehabilitated/remodelled.

## 2.7 DESIGN INADEQUACY

Prior to 1895 there was no system which could design a channel having alluvial bed and carrying silt–loaded water free from silting or scouring. It was in 1895 when Mr. R.G. Kennedy of the Irrigation Department (in those days irrigation branch) published theory of silt transport. Kennedy formula was based on a simple but incomplete concept of the mechanism which sustains particles of silt in a stream of flowing water. He observed "Sediment in a flowing canal is kept in suspension solely by the vertical component of the constant, eddies which can always be observed in any stream, boiling up gently to the surface".

He derived the formula.

$$Vo = 0.84\ mD^{0.64}$$

Where Vo is the mean velocity such that channel neither silts nor scours. He termed this Vo as critical velocity. Kennedy took the value of 'm' as unity for 'Bari Doab Canal' where he performed experiments. For coarser sand he recognized the value of 'm' 1.1 to 1.2 and for finer sand 0.80 to 0.90. He failed to make any correlation between the water surface slope and the mean velocity or the vertical depth.

Later on with the development in the design criteria the approach could be divided into two classes. The 'Regime Theory' an empirical approach developed in the plains of Indus and Ganges and the 'Rational Approach' adopted by the developed countries which gives mechanical solution of the problem by an application of the basic principles.

First definition of a 'Regime Channel' was given by Mr. E.S. Lindley in his paper as under:–

"When an artificial channel is used to convey silty water, both head and banks scour or fill, changing depth, gradient and width, untill a state of balance is attained at which the channel is said to be in regime. These regime dimensions depend on discharge, quantity and nature of bed and of bermsilt and rugosity of the silted section. Rugosity is also affected by velocity, which determines the size of wavelets into which the silted bed is thrown".

Lacey, later on, further amplified as "For regime to be established, the fundamental requirements are that the discharge should be constant, the channel flowing in unlimited incoherent alluvium of the same character as that transported, and the silt grade and the silt charge be constant (By incoherent alluvium the writer understands loose granular material which can be scoured readily as it can be deposited. . . ) so long as the alluvium material is truly incoherent, regime balance is very delicate,--------- when there is no restraint the channel will widen to obtain its correct wetted perimeter or, if too wide, may contract by throwing down very heavy berms and also scour its bed.

Since any small fluctuation in velocity, or turbulance from whatever cause must set up instability------ For true regime the channel should flow in an unlimited alluvial plain of the same grade as the material transported, there should in theory be complete freedom for later movement. A constant dischage transporting silt of a given grade tends eventually to assume a gradient solely determined by the discharge and the silt grade, the mean velocity, hydraulic mean depth and wetted perimeter. Such a constant discharge will also tend to transport a fixed 'Regime' silt charge.

Lacey introduced silt factor 'f' catering for the various silt grade and also developed relation between f & Na, where Na is the regosity coefficient.

Without going into the mathematics of these theories it can be assumed safely that Kennedy gave the irrigation engineer a direction and Lacey provided its solution. It was experienced that the channels originally designed on Kennedy's concept started widening/siltation of the bed and ultimately these were rehabilitated/remodelled on Lacey equations. It was also observed that Lacey's channels behaved well upto 500 P.P.M. silt carrying intensity. With the construction of big reservoirs it has not been possible to stick to this silt charge as the water has been rapidly changing silt intensities and other factors. Moreover during high discharges in the river the channels had to be run to meet the demand of the farmers. In the same manner it is becoming difficult to run the channels as per its authorised discharge. The variations in silt charge, and the discharge in the canals has disturbed the regime of the channels. At present there would be very few channels which could feed the tails with its authorised supply at its head. Most of the channels have been silted up in the head reach which makes the distribution unequitable i.e. upper outlets drawing excess discharge and the outlets in the lower portions start suffering. To feed the outlets in the tail reach the channels have to be run with extra water which upsets the regime further.

## 2.8 CHANGE IN CROPPING PATTERN

Due to increase in population the land holdings per family were substantially reduced. To keep up the economy of the inhabitants more areas had to be included in the Command of the Irrigation System. Due to construction of reservoirs and augmentation with ground water supply, cropping pattern has changed. The inadequacy of design and funding deferred the maintenance which ultimately resulted in:-

a) Inadequate free board.
b) Erosion of berms.
c) Inadequacy of inspection road width.
d) Deterioration of embankments
e) Erosion of slopes and siltation

of beds.

f) Higher water levels in channels resulted in more infiltration.

## 2.9 PHYSICAL PROBLEMS

Due to development of irrigated agriculture, rainfall frequency has increased and this has increased the water logging and salinity. The salt contents in the embankment have deteriorated the banks further. Burrowing animals and roots of trees are also a factor in damaging the embankments.

## 2.10 SOCIAL PROBLEMS

With the development of mechanised agriculture and increase in the cattle and human population embankments and inner prisms of channels were demaged by unauthorised crossing of people and farm animals.

## 3.0 IRRIGATION REHABILITATION SCHEMES IN PAKISTAN.

Due to deferrred maintenance, change in hydraulic parameters and because of other problems mentioned in the context the condition of the irrigation channels was going out of tune so much so that the tail portions were not getting equitable share. In the same way due to deteriorated condition of water-courses lot of water was being wasted. The urgency or the situation was realised and the following schemes for Rehabilitation and modernisation of irrigation systems were launched in the country.

## 3.1 ON-FARM WATER MANAGEMENT (OFWM) PILOT PROJECT.

In 1973 a 'Water Management Research and Investigation Project was undertaken. It was observed that water-course conveyance loss ranged between 31-57%. Based on this research, a nationwide OWFM Pilot Project for five years (1976-80) was undertaken. Its physical targets were:-

a) 1300 No. water courses to be improved with compacted earthen banks and pacca nacca (permanent masonary or concerete outlet) and 10% length lining with hard material.

b) 1,74,700 Hacters of land to be precisely levelled (2 cm deviation from average field elevation).

c) 40,000 farmers to adopt improved management practics.

Because of certain constraints though the achievement remained much less than the targets but the improved watercourses and subsequently lot of saving in water gave a big boost to the farmers. Later-on an accelerated programme for clearing of water courses was launced in 1979-80 in the Punjab Province.

## 3.2 ON FARM WATER MANAGEMENT PROJECT (FY+82 TO FY 84) PHASE-I.

OBJECTIVES (relating to water inputs) can be detailed as under:

a) Increasing agricultural production by effective utilization of irrigation ater saved through improved water management practices within individual chaks (Chak mean the area under Command of an outlet).

b) Improvement of water management technologies and institutional arrangements including organization of formal and effective water user's association.

In this project civil works include renovation programme of about 2000 water courses. Renovation involved the following components.

i) The main water course would be rebuilt with clean compacted soil.

ii) Pucca naccas would be installed.

iii) Cattle baths would be provided.

iv) Culverts to be constructed on major crossings.

v) 15% of the length of main water course would be lined in fresh water zone and 30% in saline ground water zone.

(Fresh ground water means TDS less than 1000 PPM and saline ground water more than 1000 PPM).

## 3.3. ON-FARM WATER MANAGEMENT PROJECT-II (FY 86-88).

With almost the same objectives as of OFWMI the water course renovation programme was targetted for about 2400 water courses. In the same manner as in OFWM-I the main water courses (involving nearly 85% of water conveyance) were to be demolished, realigned and rebuilt with clean compacted soil at the same site. Precast outlets (pacca naccas) would be installed (about one for each 4 hactares command) at junctions to reduce channel deterioration and water loss and to improve water-control. About 15% of the total length of the main water-course in fresh ground water zone and 30% in saline ground water zones would be lined with brick masonary or concrete to reduce water losses and/or deterioration of the water channels. In sandy soils too 30% of the farm channels would be lined.

## 3.4 IRRIGATION SYSTEM REHABILITATION PROJECT PHASE-I.

This project was started in the year

FY 83 and was originally a 3 year project but later on extended upto Fy 88. This project provides rehabilitation of surface irrigation and surface drainage systems (irrigation channels above outlets and surface drains) that have been deteriorated because of deferred maintenance.

OBJECTIVES

a) To increase agricultural production by:–

   i) providing a more reliable water supply by reducing risk of failure in the irrigation net work and

   ii) reducing crop losses resulting from rain flooding by improving the surface drainage system.

b) To provide more equitable irrigation water supply to all farmers by increasing deliveries to water courses in the tail reaches of the minors and distributaries through a program of silt removal from the selected channels.

c) To strengthen the capability of the irrigation deptt's operation and maintenance programme so as to improve efficiency of system operations and assure continued maintenance of installed facilities and

d) To serve as a Phase–I model of larger and continuing programme of a similar nature that could be replicated in future projects.

The project provided earth work, stone pitching and repair of hydraulic structures for about 14000 K.M. of canals as well as cleaning and resectioning of about 3500 K.M. surface drains.

3.5 IRRIGATION SYSTEM REHABILITATION PROJECT–II.

The second Irrigation System Rehabilitation project (ISRP II) would be launched during the years Fy 89–83.

OBJECTIVE:

a) The objectives of Phase–II would be almost the same excepting in paragraph (b) redesign of channels & outlets has come in and for this aspect the department's design capability would be improved. 4,135,000 hactares would be benefitted by the rehabilitation of canals and 825,000 hactares would be reclaimed with the rehabilitation of drains.

ISRP–I was supposed to rehabilitate the channels which have been deteriorated due to defferred maintenance. ISRP–II would take care of inner prisms of the channels also. In otherworld in ISRP–II the problematic channels would be redesigned taking care of existing hydraulic parameters.

## 3.6 COMMAND WATER MANAGEMENT PROJECT (FY 85–89).

This project has been launched mostly to integrate the activities elaborated in OFWM & OFWM & ISRP projects and in addition to strengthen the management of the existing institutions, infrastructure, agricultural inputs and services so as to remove major constraints of irrigation and agriculture inputs in the selected areas.

OBJECTS:

a) increase agricultural production through improved water managements, alongwith efficient supplying of agricultural services and non water inputs.

b) develop water management techniques and programmes replicable over a wide range of agroclimatic zones.

c) build within the provincial agencies a continuing capability for planning, implementing, operating and maintaining integrated and efficient programmes of irrigation agriculture and

d) Strengthen farmer participation in formal water user association to improve their overall water and non–water input managment and provide them an opportunity to have a stronger voice in decision making.

The project would provide canal remodelling, canal rehabilitation (including lining of distributaries and minors upto one cubic meter per second discharge), construction of surface and sub surface drainage system (Tubewells or Tile drainage,) remodelling of hydraulic structures, rehabilitation and lining of main water courses (upto certain %age), and strengthening of insituations and improving non–water inputs (precision land levelling, demonstration plots credit system etc. etc.) The staff would also provide guidance to the farmers on applying and scheduling irrigation water to their fields. The following works were envisaged.

| | |
|---|---|
| Remodelling of outlets | 1325 No. |
| Renovation of water courses | 1050 No. |
| Lining of Distys & minors | 250 k.m. |

## 4.0 PERFORMANCE OBJECTIVES:

### 4.1 TO IMPROVE WATER MANAGEMENT BY INVOLVING FARMERS PARTICIPATION.

In accordance with the rules in vogue the operation and maintenance of the irrigation system up–stream of the water course is to be done by the Govt. and down–stream of the out let, i.e. the O&M of the water courses, is the responsibility of the farmers. The warabandi (i.e. weekly rotational schedule of irrigation deliveries to farmers) is supposed to be formulated by the farmers themselves and the department comes in picture only whenever there is a dispute amongst the water users and the department is requested by any share-holder for framing warabandi. In absence of any organization of the farmers it used to be difficult to bring all the water users of an outlet on one platform. The Punjab Government had therefore to promulgate a "Water Users Association Ordinance" in 1981 to fulfill the objectives of On Farm Management Project. The association, jurisdiction was confined to the share-holders of a water course. Some of the engineering functions of Water Users Association are detailed below:-

i) improve, rehabilitate, operate, reconstruct and maintain the water courses.

ii) improve sub soil or surface water supply.

iii) install own, operate and maintain tubewells and lift pumps.

iv) uprade and maintain farm ditches and field outlets.

v) encourage adoption of improved on-farm water use and management practices and other improved land and agricultural input practices.

vi) participate in programmes to improve water courses, land levelling and agronomic practices, and to lease own, operate and maintain equipment structures and other matters associated with improvement efforts.

vii) arrange labour for emergency repair of water courses.

and

viii) remove obstructions in water courses during realignment, operation and maintenance.

4.2 To increase crop production by improving/ensuring regular irrigation supply.

4.3 To improve the command of the irrigation channels by lining, reduce the value of 'n' and design the channels at a flat slope, and utilize the command saved in the water-course downstream.

The objectives listed in (4.2) & (4.3) above could be achieved to a great extent if the irrigation channels are lined. The seepage losses which go upto 10-15% could be saved and utilized for irrigation purposes. The flatter slopes of the channel beds by adopting low values of regosity coefficient would improve the command of the outlets. As far as ensuring regular supply, efforts need to be made to operate the channels always on full supply. If at all the rotational closure, due to shortage of supply, is necessary, it should be done in such a way that no farmer misses more than one turn. Discharge measuring devices not at the cost of the command, at places where possible should be installed to monitor quantum of the discharges.

4.4. To improve surface and sub-surface drainage system of the area.

At present the farm drainage is almost non-existant. Water user association should be encouraged to take over this job of constructing farm surface drain. Technology for laying sub-surface drain (Tile drainage) is new to this country, this should continue to remain with the Govt's agencies.

4.5. To provide equitable distribution of irrigation supply.

Outlets where-ever required, may be remodelled so as to share excess/shortage of the supply in the parent channel proportionately.

4.6. To improve the operation and maintenance of the irrigation channel.

As stated earlier cattle and farm vehicle tresspass attribute quite a lot in damaging the canal banks and berms. This could be checked if this responsibility too is entrusted to the farmers. It could be tried from minors and if found successful could be extended upto distributaries.

4.7 To organise an infrastructure for improving non-water inputs.

Improving of non-water inputs must go side by side with the improvement of irrigation canals and water courses. All such agencies should be closely associated with water user associations so that the required facilities are available to the farmers at the door.

4.8 To organise training fo the farmers as well as of management staff.

Most of the farmers in Pakistan are not well educated to keep themselves informed about the latest development in the field of Agriculture and Irrigation. Both these departments must impart training to the farmer community right in their villages and guide them about the latest techniques. Model farms need to be established in the villages where the farmers could be exhibited application of water and Non-water inputs.

5.0 PERFORMANCE CRITERIA.

5.1. The cost of the civil works per hactare should be kept at a minimum level.

Since the O&M cost of the civil works has a direct bearing on the recovery of water rate from the farmers, this cost should be kept minimum. This is possible only if the irrigation system works efficiently, its inner prism remains unchanged with the variations in hydraulic parameters and each outlet takes its appropriate share of water and silt. Lining of the channels can play a major role in reducing O&M cost.

## 5.3. CROPPING PATTERN:

Latest techniques need to be developed to maintain a crop/water balance. The age old practice of irrigation by flooding is not at all scientific and may be reviewed. Non scientific application of water could be taken as one of the major reasons for not getting appropriate yield from the crop inspite of the fact that Pakistan has world's biggest contiguous open-channel irrigation system. Before commencement of canal-irrigation era in Pakistan the land was lying mostly uncultivated excepting a few patches of irrigation either by persian-wheeled well along the banks of the rivers or rainfed in the interior. The population was low and its requirement of food and fibre was much less as compared with of to-day.

With the advent of irrigation by flow it was considered more feasible to bring as much area under command as possible without taking much care for the crop-water requirement or its yield. A big amount of water seeped through the soil and caused water logging problem later on. At that time (almost 100 years back) this type of irrigation may be the only method to fit into the socio-economic environments of the country. The knowledge of crop-water balance in those days was not so much developed as it is today. It is, therefore, need of the hour to switch over to the system based on water demand worked out for each crop. It may not be possible to change the age-old system in one go but it could be initiated as a pilot project on some of the water courses where the response from the farmers is positive and the hydraulic conditions of the channels also permit e.g. where the channels have been lined on non-silting velocities and free board is adequate to accommodate more water at times of more demand. The outlets could be redesigned to record the variations in discharge. Advisory cells could be established guiding the farmers when and how much water is required for each crop. Computer programming could be prepared for the purpose. This system, if works well, could be extended later on to a bigger area.

5.4 As stated earlier water user's associations have since been organised. The association is responsible for reconstruction, maintenance and improvement of a water course with the funds to be generated by the irrigators themselves. The association is to work under the direction of the field officer to be appointed by the Govt. In case of any dispute amongst the irrigators the decision of the Field Officer would be final and binding. This is a encouraging break-through which has been under taken. With its successful achievement more responsibilities like framing of warebandi, distribution of non water inputs inclusive of machanised equipment etc. could be entrusted to water users association. These associations can run agro-based industries and become self financing units. Later on the O&M of the minors could also be made their responsibility.

## 6.0 MODEL FOR SELECTING CROPPING PATTERN BASED UPON WATER SUPPLY AND YIELD PARAMETERS.

6.1 In Pakistan the water available in the canals for irrigation is much less than the demand and a fixed discharge is delivered on weekly basis excepting when the channels are closed for rotational or annual closures. The farmer is therefore under pressure to irrigate during his turn whether irrigation is required or not. This leads to very ambitious cropping patterns and results in low yield per acre.

Keeping such state of affairs in view, on some of the selected water courses in Command Water Management sub project, the computer modelling on Pilot basis has been initiated with a basic approach to deliver water on demand to crops. Assuming that water is continuously available excepting annual closure and taking input due to historical rainfall, the resulting balance is prepared on monthly basis. Two alternatives plans have been prepared.

i) First plan examines the cropping pattern in the case where water is available to meet the crop water requirement, through the year.

ii) 2nd plan examines a possible pattern if irrigation efficiencies below the outlet are improved.

The data from the selected water-courses shows a deficit of almost half of water requirement in the months of October, January, February and March. The yield data and water deficit analysis was used in combination with the crop prices, yield per acre and production cost per acre. A complete economic analysis was worked out adopting different patterns. The result is depicted below:-

Annual net income for the water-course with 143% cropping intensity. Rs. 0.258 Million

(following the existing procedure)

With cropping pattern to meet crop water requirement and intensity of 92% the net comes Rs. 0.453 Million

Where improved efficienty due to maintenance, agronomic and irrigation practices is used, intensity 124%. (ideal condition). Net income Rs. 0.609 Million.

To assess the impact of water deficit on yield a simple calculation using the method proposed in FAO Irrigation and Drainage paper No. 33 yield response to water was made by the Consultants. Calculations were based on the following relationship.

$(1-ya/ym) = KY \quad (1-Eta/Etm).$

where

ya = the actual yield.

ym = the maximum yield under well irrigated conditions.

Ky = an empirical constant for individual crops.

Eta = the actual evapotranspiration.

Etm = the maximum evapotranspiration.

This computer model is just an introduction to the irrigation system and would be developed with the time taking more factors in view.

## 7.0 CONCLUSIONS:

7.1. With the construction of big storages like Mangla and Tarbela, the silt load in the channels, varies rapidly with the season and it comes down to negligible during winter. As recounted in the foregoing pages the Lacey channels are capable of carrying about 500 PPM of silt intensity. In some cases it may not be possible to restrict the silt entry upto this limit. The channels designed on Lacey's concept have worked well for a long time but with the varying silt charge the Lacey's approach needs updating. The main flaw in the Lacey's approach is absence of sediment charge. Though the effect of increasing Lacey's silt factor 'f' is same as increase in the sediment-carrying capacity of canal yet there is no direct corelation between Lacey's 'f' and the carrying capacity of the canal.

The change of design criteria therefore becomes necessary to get most efficient working of the channels and its structures, ultimately resulting in equitable distribution of supply in the outlets. The modified hydraulic design criteria is being devised and would be adopted in Irrigation System Rehabilitation Programme II.

7.2. Continuous deposition of silt in the field raises the land levels and it affects the command. With the increase in population and to meet the need of food & fibre it has become imperative to line the channels with low values of rugosity coefficient and attain a flat bed slope. It has been observed that in an earthen channel of 1 cubic meter per second capacity, head of 0.3 meter could be saved in a length of 7 k.m.

7.3 Rehabilitation work is to be carried out to strengthen the embankments of the canals. Inside of the prism berms could be created as per design to provide additional safety device against breaches, plantation is to be grown only on the outer toe of the banks. Turfing could be provided on the dowels as well on the outer slopes of the embankment to check erosion due to rain fall. Sand core in the banks may be laid where rodents are active.

7.4. Pilot schemes to run the supply on actual demand basis on some of the selected water courses (where the land holdings are big and farmers are willing to cooperate) may be initiated. Better farm practices like irrigation in furrows, surge irrigation, sprinkler and drip irrigation need to be introduced where ever possible. Water demand of the crop must be met with. In the extreme cases where the adequate supply is not available, the intensity of irrigation could be reduced to obtain relatively better output from crops.

7.5 Suitable cropping pattern in areas, after field studies in demonstration plots, must be introduced to get maximum benefit from the irrigation.

7.6. Water users associations need to be strengethned further to handle the jobs detailed in the text.

7.7 Farm drainage, (surface and sub surface) should be extended to drain out the storm water and the salt contents from the land. The sub soil water should be kept out of the root zone.

# SHELL FOUNDATIONS

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## 1. INTRODUCTION

Even though shells have been enjoying wide and varied use in roofs, they are newcomers to the family of structural foundations, and it is less than three decades only since Candela poured his first shell footing on the Mexican soil. What however may appear strange is the fact that the concept of shells itself is not new in foundations, if one would consider the old inverted arch foundation as belonging to this group. It may be noted that use of brick arches in foundations has been in practice for a long time in Indian subcont–inent.

It is needless to say that the twin attributes of shell which recommend its use in roofs are economy and aesthetics. Since the latter aspect is of no concern in a burried structure like the foundation, it is the aspect of economy which holds the key to the acceptance and use of shells in foundations. In other words shells hold prospect for adoption in foundations only if they can project themselves as economic alternatives to the conventional plain foundations. Shells are structures which derive strength from 'form' rather than 'mass' which enable them to put a minimum of material to maximum structural advantage. High material cost and cheap labour are typical characteris-tics of most of the developing countries which are highly favourable for economic use of shells. It has been found in respect of foundations that in situations involving heavy column loads to be transmitted to weaker soils large areas of foundations become necessary and a situation analogous to large spans in roofs develops. The scope of economy with shells becomes immediately apparent under these circumstances.

i) Shells used in foundations are invariably characterised by smaller size, but greater thickness and depth, compared to those used in roofs. This fact assumes considerable significance when it comes to the analysis of shells.

ii) Since foundation shells bear directly on soil at their bottom and carry backfill on top, besides being deep and thick, the problem of buckling is of lesser concern in foundation shells when compared to roof shells.

iii) Shell foundations can be cast insitu on earth cut to the required profile; no formwork is necessary except perhaps at the sides. This

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fact has an important bearing when considering the relative cost of shells in roofs vs. foundations.

## 2. DIFFERENT TYPES OF SHELLS USED IN FOUNDATIONS.

Even though a variety of shells lend themselves for adoption in roofs, those that can be judiciously adopted for use in foundations are far too few. The following is an account of some of the more common types of shells used in foundations, and their geometric characteristics which enable them to perform their assigned functions efficiently and effectively in foundations under different circumstances.

### 2.1 The Hyperbolic Paraboloid

The hyperbolic paraboloid, or hypar is a shell which is known to combine great elegance with versatality, and among the shells which are used in foundations. This is the one which has enjoyed the widest application. It is a doubly curved anticlastic shell. It is a shell of translation as well as a ruled surface, the latter property being the result of its anticlasticity. It can be said of this shell that it is structurally as efficient as it is geometrically elegant.

#### 2.1.1 Geometry of the Hypar Shell

As a translational surface the hyperbolic paraboloidal shell is generated by moving a concave parabola over a convex parabola, as shown in Fig. 2. This leaves a surface formed of two sets of parabolae at right angles to each other. When these parabolae are indentical we have a rectangular hyperbolic paraboloid. On a rectangular hyperbolic paraboloid it will be seen that along directions inclined at $45^e$ to the directions of the principal parabolae, the surface consists of straight lines of varying inclinations, but parallel and at right angles to each other in plan, which make it a ruled surface (doubly ruled) as well. These straight lines are also called the generators of the surface. If we now take horizontal planes i.e. parallel to the x–y panel, it is easily seen from the equation of the shell that these horizontal planes intersect the shell along rectangular hyperbolae, of which the straight line generators are the asymptotes. The shell acutally derives its name from the fact that its surface is made up of parabolae and hyperbolae as described above. From the engineering point of view, however, the most versatile aspect of the geometry of the shell is its straight line property, which gives it all the advantages of a shell and at the same time that of a plain surface. This property is effectively exploited in making the formwork, laying the reinforcement and casting and finishing the shell in the case of roof, and profiling the soil, making the reinforcement grill and casting and finishing the shell in the case of the foundation.

The surface area of the hypar needs to be known in connection with estimating quantities of materials. An approximate formula for the same is given follow.

$$S = ab\left[1 + \frac{1}{3}\left(\frac{f^2}{a^2} + \frac{f^2}{b^2}\right)\right]$$

where a and b are plan dimensions $f$ is rise

It can be seen from this equation that the surface area of a square hypar shell exceeds the area of the projected square by nearly a third of the square of the rise.

The volume of the space enclosed between the shell quadrant and its rectangular projection is obtained as

$$V = \frac{abf}{4}$$

This is a quarter of the volume of the rectangular prism of section a x b and height f.

### 2.1.2 Umbrella Footing

Among the combinations of hyperbolic paraboloidal shell used in roofs, one of the early favourities has been the "inverted umbrella roof" resting on central columns, shown in Fig. 3(a) it is the success with this form that has given the clue for trying this combination in foundation, where, in an upright position they can serve as foundations for columns, Since they have the inverted umbrella shape further inverted, they have come to be called "Umbrella Footings". The hyperbolic paraboloidal shell, whether in roof or foundation, owes much of its present-day popularity to the pioneering effects of the famous Mexican Engineer-Architect, Felix Candela. He is also the father of the concept of modern shell foundations and demonstrated it for the first time by constructing hypar footings of the above type for the Mexico City Customs House in 1953. Since then he has poured a large number of such footings in Mexico and else-where, all of which are reported to have performed exceedingly well. It may be interesting to note that many of his columns supporting inverted umbrella roofs are in turn supported on umbrella footings as shown in Fig. 3(a). And like their counterpart on top, they generally consist of four numbers of hyperbolic paraboloidal shell quardrants joined together by a system of edge and ridge beams (valley beams in the case of roof), the latter terminating at the column base at apex. The geometrical particulars of a footing of this kind are shown in Fig. 3(b). The use of hyperbolic paraboloidal shell, in the umbrella type of combination described above, is not limited to individual footings. They can be extended as combined footings for two or more columns in one row Fig.3(d). Another possibility of a hypar raft is shown in Fig. 3(e) Note the single unit for four columns shown hatched. This is again the offshoot of the hipped hyperbolic paraboloidal roof on four columns of which it is the inverted copy. This roofing is sometimes called "Umbrella Roof" in which case the corresponding foundation should be called "inverted umbrella foundation." But since this form gives rise to certain practical difficulties particularly in the matter of providing adequate soil support below its uneven edges it is not likely to find favour with foundation engineers.

## 2.2 The Cone

Next to hyperbolic paraboloid the shape most favoured for column footings is the cone. It need hardly be mentioned that few shells can match the cone in the simplicity of its shape.

Reinforced concrete, rotationally symetric, truncated conical footings of the type shown in Fig. 4(a) is probably the simplest form in which a shell can be put to use in foundations. The provision of radial and circumferential reinforcement is as simple as for a circular flat footing while the construction is probably only a little more difficult. The shell may be of uniform thickness, or the same can be made to vary along the generator. However, on account of its circular plan the use of conical shell is limited to individual footings, unlike hyperbolic paraboloid which could be used for combined footings or rafts as well. The ring beam shown at the bottom in Fig. 4(a) is optional.

Cones of substantially larger dimensions can also serve as foundations for tall structures like chimney shafts, in place of the conventional circular or octagonal rafts Fig. 4(b) The cone should be in perfect contact with soil throughout its bottom surface, besides the surcharge that comes on top of it.

While the cone is a suitable type of foundation for the uses mentioned above, the majority of instances in which conical shells have been adopted are for tall telecommunication towers (television, radio, telephone, etc.), where they serve not as regular foundations of the type described above, but as substructures linking the tower shaft to the annular raft or ring at the bottom Fig. 5(a) which is the actual foundation bearing on soil and transmitting loads to it. Such a transition from the shaft above to the ring below has been necessitated on account of the fact that the dimensions of the ring foundation, as demanded by the soil conditions are substantially bigger than that of the shaft. The space within the flanged conical structure is free and is often utilised for services. Very often these cones are stiffened internally, the stiffening taking various forms, one such form is shown if Fig. 5(b), to resist moments and shears due to wind etc. Prestressing is recommended for the hoop reinforcement in the cone as well as the foundation ring to prevent or limit the width of cracks in concrete. A large number of such tall towers mainly for television with truncated conical shells as substructure have been constructed in Europe and elsewhere in the last few decades, starting with the famous Stuttgart tower in West Germany designed by Prof. Leonhardt and constructed in 1955. The German landscape is today virtually studded with such towers. As far as the height of the tower is concerned, the tallest is the Moscow tower (533m) followed by those at East Berlin and Munich Fig. 5(c(.

## 2.3 Inverted Dome

For circular structures of overhead structures like water tanks supported on a circular row of columns, thin inverted domes can serve as economic alternatives to thick cirular or annular raft foundations Fig. 6. The transfer of column load to the inverted dome can be effected through a ring beam at top as shown in the figure. Other shells of revolution like the rotational paraboloid can also be tried in place of the spherical dome, to serve the same purpose.

## 2.4 Elliptic Paraboloid

The elliptic paraboloid shortened as 'elipar' is a doubly curved synclastic shell. As a translational surface it is obtained by moving one parabola over another Fig. 7(a), both parabolae being curved in the same direction (concave upwards for the foundation.) The difference between the elipar and the hypar is that these parabolae are curved in opposite directions in the case of the latter. The shell derives its name from the fact that horizontal planes intersect the surfaces along ellipses (which were hyperboale in the case of the hypar).

An inverted elipar of the above type bounded by parabolae, and with edge beams, can be tried as foundation for rectangular also square structures, or structures supported on a rectangular or square row of columns, as shown in Fig. 7(b). Unlike the inverted dome and the cone its use is by no means confined to single units, but can be extended to rafts for a number of columns, where the normal alternative would be a beam and slab raft, whose plate elements these shell elements replace Fig. 7(c) They may also prove economic over the other alternatives viz, a flat slab raft, or grid raft (non-continuous raft consisting essentially of two sets of beams intersecting at right angles.) Note that the above plain counterparts apply in the case of single rectangular or square units as well.

A further point to be noted is that in place of the ellipatic paraboloid, singly curved shells like cylindrical shells (circular or parabolic) and folded plates can also be tried for use in rafts.

## 2.5 Funicular Shells

These are a class of shells for which the end product of the analysis is their geometrical shape, and not the state of stress, as with normal shells. In the case of a regular shell we start with the geometry of the shell, and for a given loading and boundary conditions, we arrive at the state of stress needed for design, In the case of funicular shells we carry out the reverse process of investigating and arriving at the geometric shape of the shell that will give a desired state of stress for the given loading and boundary conditions. As far as a desirable state of stress is concerned, it would be universally agreed that the most desirable one would be a state of uniform compression unaccompained by vertical shears or moments. A point that needs to be appreciated, however, is that a funicular shell is funicular only under the prescribed set of loading and boundary conditions, which means that there is any change in either of them, the state of stress can get altererd..

As far as foundations are concerned, since a funicular shell is not limited by plain shape, it can serve the uses already mentioned for inverted dome and elliptic paraboloid, either in single or multiple units. It would be of considerable interest to investigate funicular footings for single columns too, under a variety of loading and soil conditions.

## 2.6 Folded Plate Foundations

A typical folded plate that can be considered for use as foundation is the pyramidal combination of four inclined trapezoidal plate elements, that can support a column at its centre Fig. 8. Note that the term pyramidal footing is frequently used for the solid pyramid used as footing. When this is made hollow Fig. 9 One gets the folded plate type of footing described above. Since these pyramidal folded plates can be rendered square or rectangular in plan, they can be combined to form multiple units to serve as combined footings or rafts, as could be done with hyperbolic paraboloid.

A few examples of shells other than those given above that can serve as foundations are illustrated in a paper by Bolcskei from which one example of a folded cone shell that can take the place of an annular raft, is reproduced here for reference Fig. 10. Further possibilities in respect of tower shaped structures are shown in Fig. IIa, b, c.

## 3. CONCLUSIONS

What has been said above is no exhaustive list of shells for use in foundations. Shell foundations are potentially economic under conditions of heavy loads to be transmitted to weaker soils. Since their economy is mainly the result of the savings in materials they offer, it is obvious that overall economy with them should be more pronounced in countries where material costs are high compared to labour costs. Shell foundations enjoy the widest use in countries of Latin America, in particular Mexico, east European countries, the Soviet Union, some countries of Africa and India. It is hoped that this introduction to shell foundations shall give some impetus for the use of shells in foundations. With steel cost increasing, the concrete towers would be not only economical and beautiful as compared to steel towers but also maintenance free and long lasting.

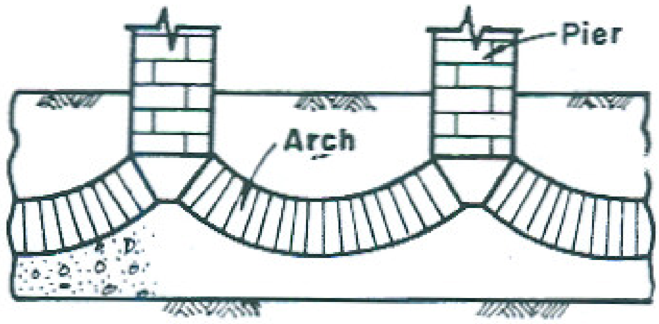
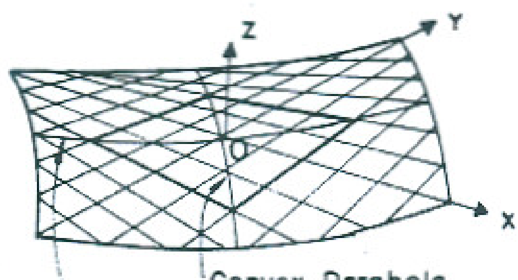



FIG. I INVERTED ARCH FOUNDATION




( a )

FIG. 2 GEOMETRY OF THE HYPERBOLIC PARABOLOID

(a) HYPAR BOUNDED BY PARABOLAE

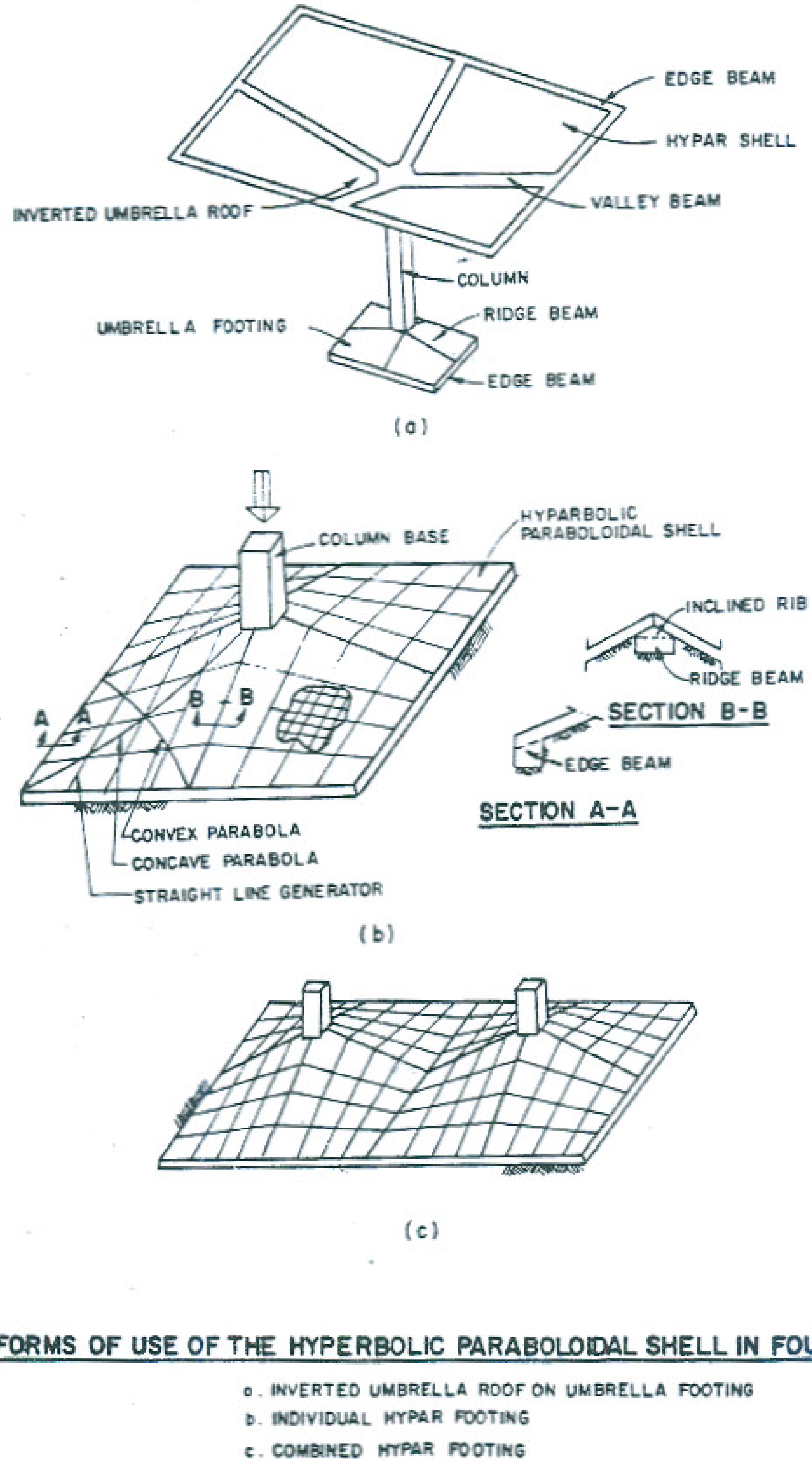
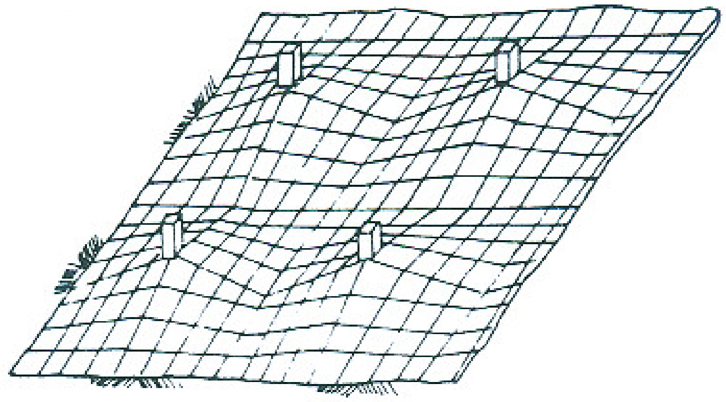



FIG. 3 FORMS OF USE OF THE HYPERBOLIC PARABOLOIDAL SHELL IN FOUNDATIONS

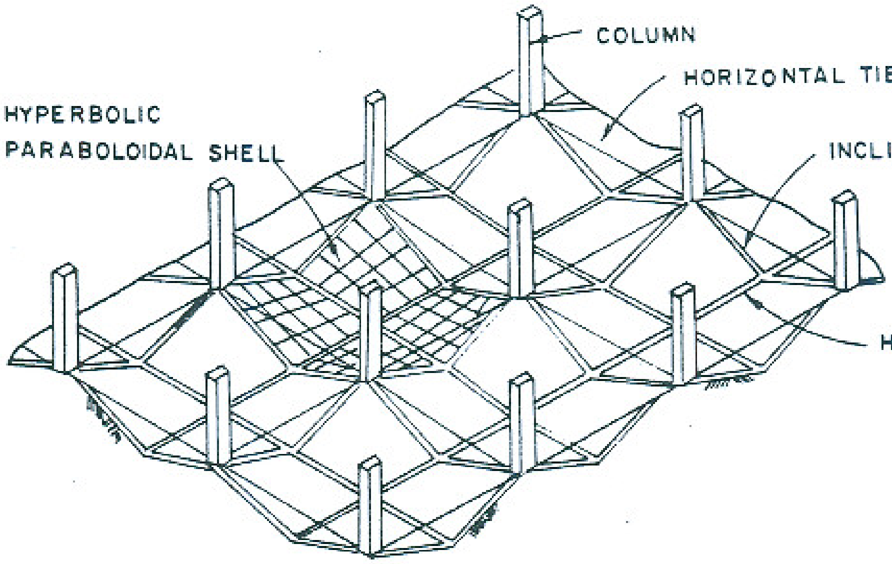
a. INVERTED UMBRELLA ROOF ON UMBRELLA FOOTING

b. INDIVIDUAL HYPAR FOOTING

c. COMBINED HYPAR FOOTING



( d )




( e )

**FIG.3 (Contd)** FORMS OF USE OF THE HYPERBOLIC PARABOLOIDAL SHELL IN FOUNDATIONS

d. HYPER RAFT

e. HYPER RAFT( Invented Umbrella Type)

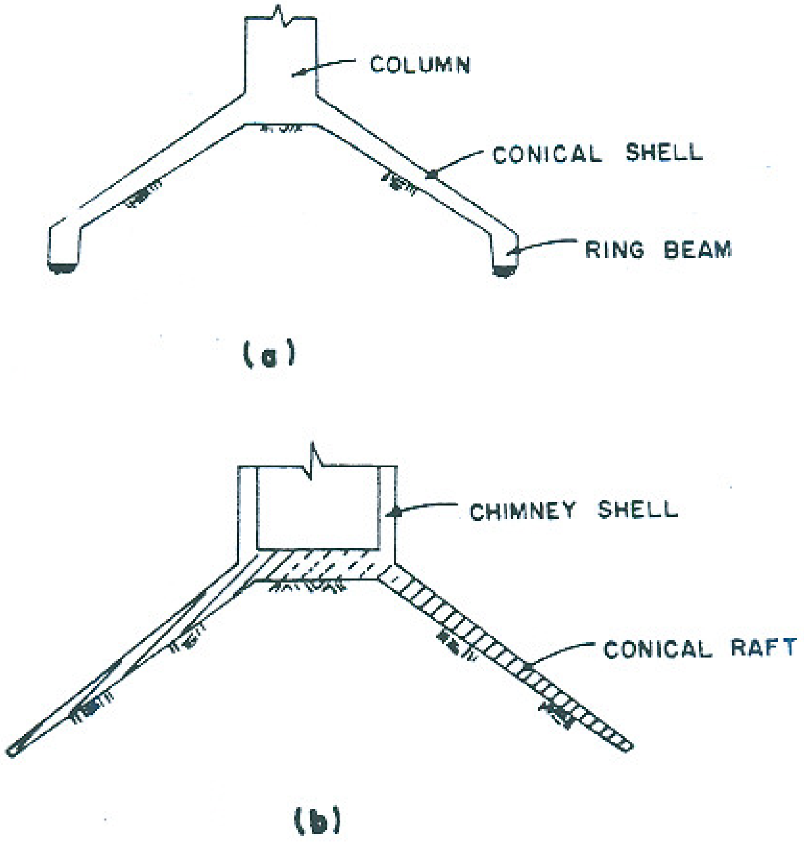



**FIG.4 CONICAL SHELL FOUNDATION**

a. COLUMN FOOTING
b. CHIMNEY RAFT

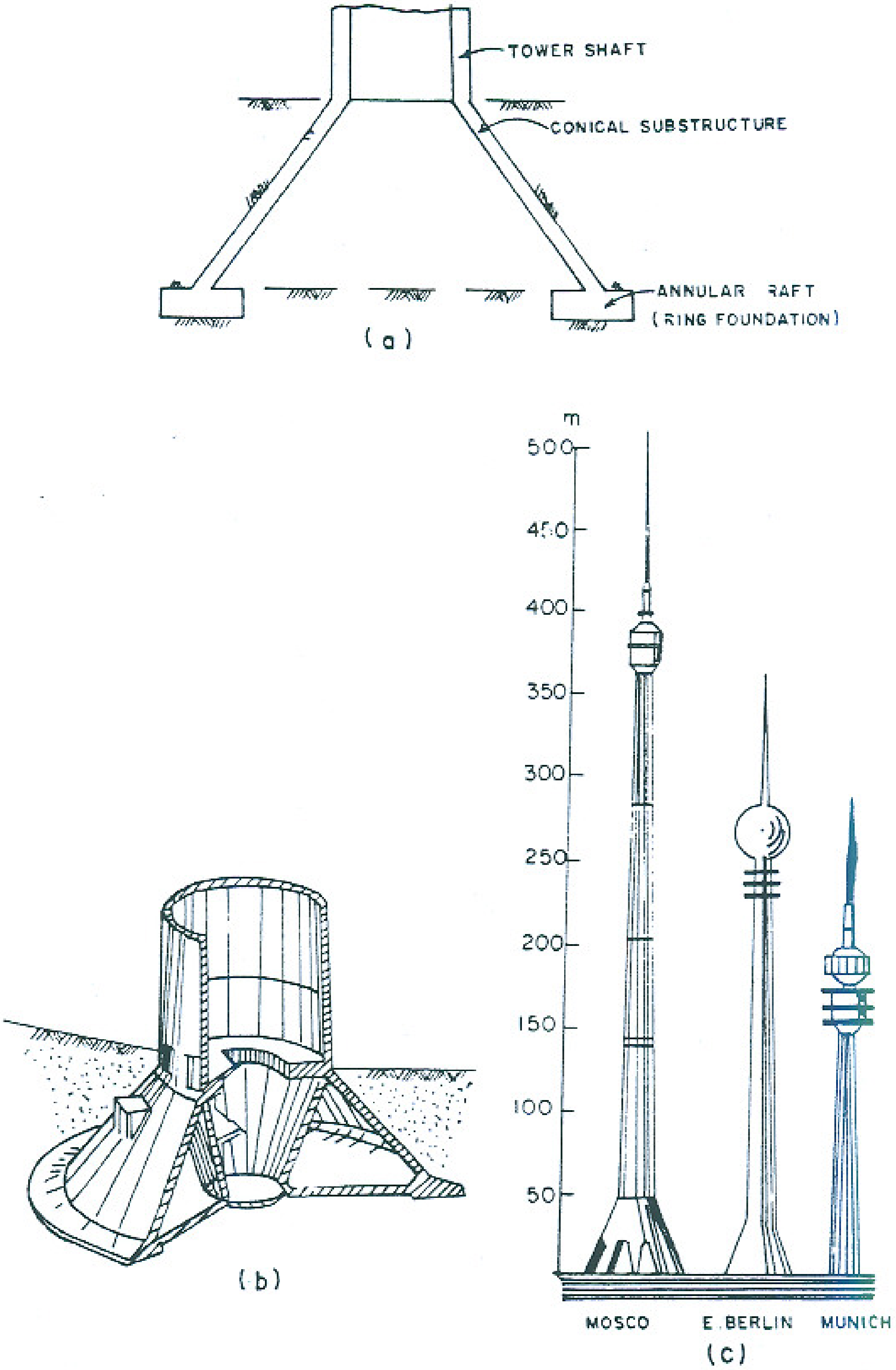



Fig.5 CONICAL SUBSTRUCTURE FOR TELECOMMUNICATION TOWERS.

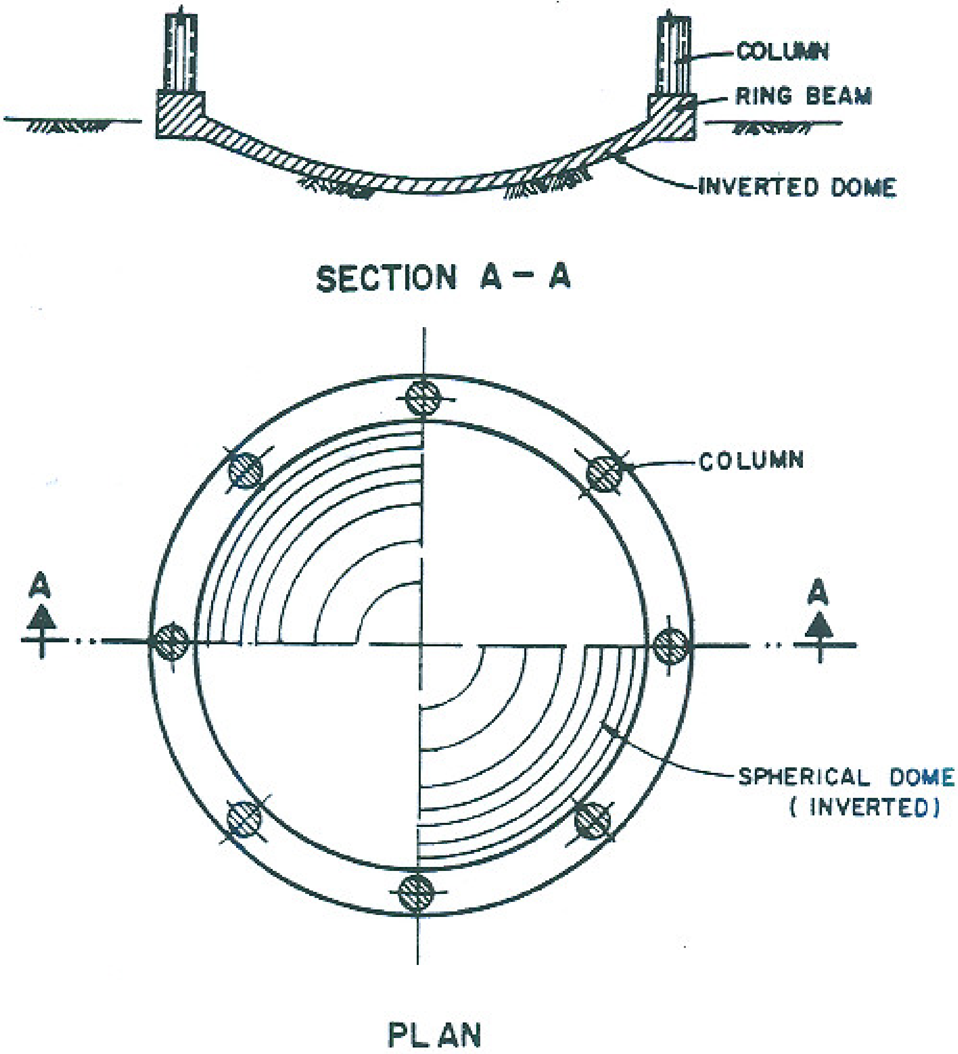
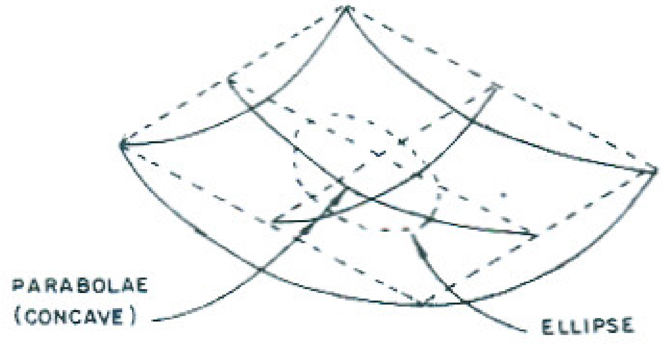
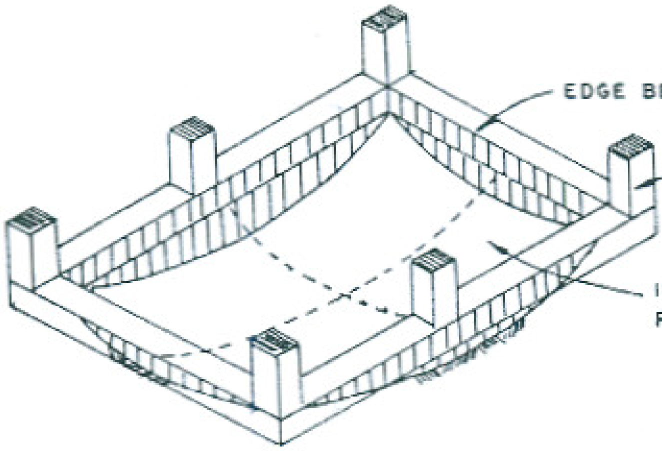


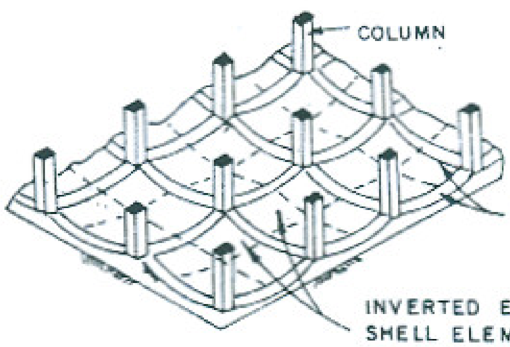

FIG. 6 THE INVERTED SPHERICAL DOME RAFT




(a)




(b)




(c)

FIG.7 ELLIPTIC PARABOLOIDAL SHELL RAFTS

a ELLIPTIC PARABOLOID
b ELLIPTIC PARABOLOIDAL RAFT( Single Shell)
c ELLIPTIC PARABOLOIDAL RAFT( Multiple Shell)

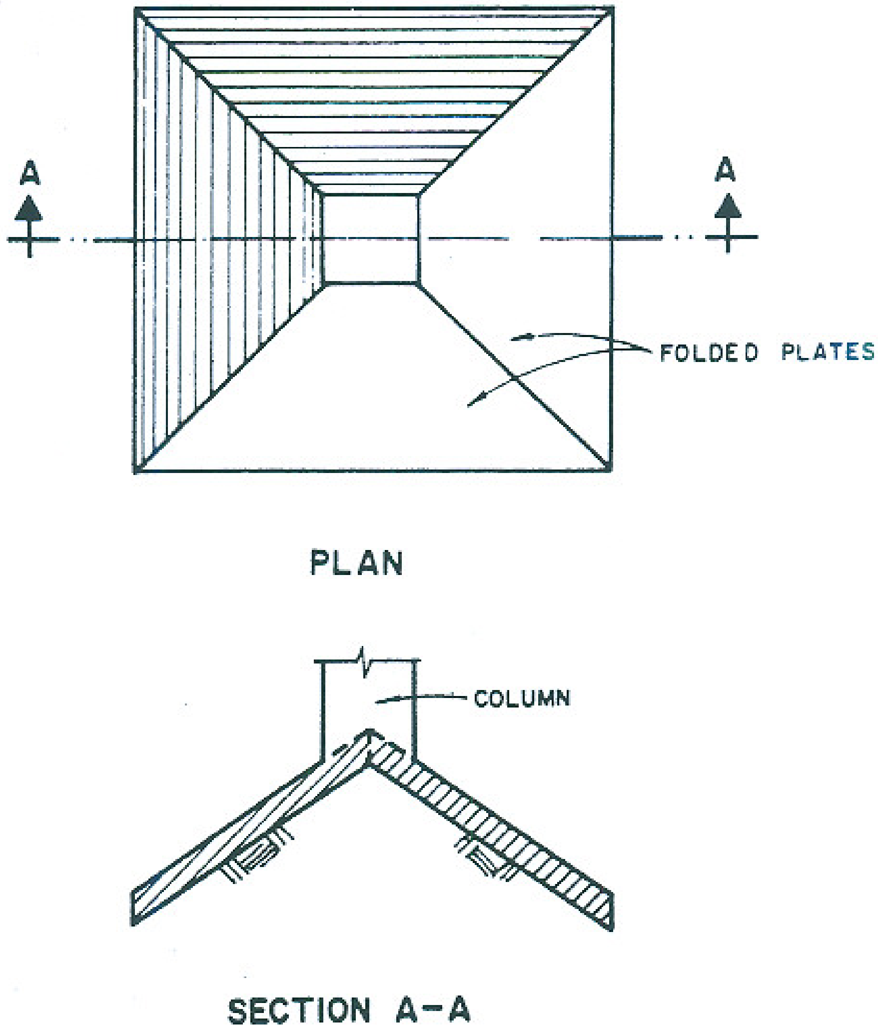



FIG. 8 FOLDED PLATE FOOTING

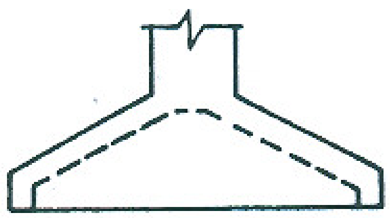


FIG. 9 HOLLOW PLATE FOOTING