9. *STRUCTURAL ASPECTS OF FLOOD CONTROL*

9.1 INTRODUCTION

Devastating floods in the 50s made the country launch flood control programmes at the national level. The four phases of the programme included, immediate measures, short-term measures, long-term measures and beyond long-term measures [106].

The immediate measures proposed by the programme included embankment at selected sites, revetment and spurs as measures to protect town and important installations against river erosion. The short-term measures included the measures for channel improvements and embankments. On the other hand, the long-term measures proposed construction of selected storage reservoirs in tributaries of certain rivers at suitable sites and additional embankments wherever necessary.

As against the total of 40 million hectares prone to floods, area of about 15 million hectares have been protected by construction of embankments. A number of dams and barrages have been constructed. The State Governments have been assisted to take up mitigation programmes like construction of raised platforms etc. Floods continue to be a menace however mainly because of the huge quantum of silt being carried by the rivers emanating from the Himalayas . This silt has raised the bed level in many rivers to above the level of the countryside. Land use regulations, on the other hand have not been implemented for the safety of the inundated land. Embankments have also given rise to problems of drainage with heavy rainfall leading to water logging in areas outside the embankment. The Task Force for Flood Management and Erosion Control under the Central Water Commission has defended the role of the embankments in providing protection from floods [107].

In this chapter various structural aspects of flood control measurements have been examined for their effectiveness and design details. Based on the Central Water Commission's flood manual recommendations, embankments have been constructed on most big rivers of India, besides the construction of dams which also serve other purposes from their reservoirs. Case studies on river Sabarmati in Ahmedabad and Tapi in Surat have been done each for embankment and dam effectiveness against floods. Earth reinforced Panel Retaining wall has been compared with the conventional RC Counterfort retaining wall. Design criteria for seismic conditions have been given for retaining walls as embankments. The effective use of dams for flood control and the risks in case of flash floods have also been discussed briefly.

9.2 STRUCTURAL MEASURES FOR FLOOD MANAGEMENT

9.2.1 Levees and Flood Walls

The principal purpose of levees and floodwalls is to confine floodwaters to the stream channel and a selected portion of the floodplain [122]. These barriers protect only the land area immediately behind them, and are effective only against flood depths up to the chosen level for which they were designed. Levees are normally constructed of earth and require significant space to accommodate the required base width. Floodwalls are usually constructed of concrete or steel and take up far less room. They are more suitable for use in congested areas.

9.2.2 Channel Modification

Normal natural watercourses have a river channel of limited capacity, which may be exceeded annually, with excess floodwater overflowing onto the floodplain. Hydraulic improvements to the watercourse or to the floodplain, and flood channels constructed within the floodplain, enable flood waters to be passed at a lower level than would occur naturally. In urban areas, such works also permit the optimization of land use through improved residual drainage. Various types of channel modification include-straightening, deepening or widening of the channel;

raising or enlarging bridges and culverts which restrict flow; removing barriers which interfere with flow; installing river training works. Channel modifications are similar to levees and floodwalls in that they can be used to protect a specific site or region.

9.2.3 By-Pass Floodways

These structures serve two functions in flood mitigation. Firstly they create large, shallow reservoirs which store a portion of the flood water and hence decrease the flow in the main channel below the diversion. Secondly, they provide an additional outlet for water from upstream, improving flow characteristics and decreasing water levels for some distance below the diversion. Diversions intercept flood flows upstream of a damage-prone area and route them around the area through an artificial channel. Diversions may either completely re-rout a stream or collect and transport only those flows that would cause damage. Diversions are particularly well suited for protecting developed areas, because they do not usually require land acquisition or construction within the protected area. However, nature of local land formations and soil conditions pose limitations for diversions. There must also be a receiving water body or stream channel with sufficient capacity to carry the flow bypassed through the diversion without causing flooding.

9.2.4 Retarding Basins and Flood Storage Areas

Flood storage and retardation involves the deliberate, controlled flooding of designated areas in order to minimize overall flood losses. It permits floods exceeding a specified magnitude to spread over low-lying lands situated behind embankments in a controlled fashion, accomplished by the operation of gated structures or spillway sections incorporated in the embankments. The diversion of floodwater, when carefully controlled, will reduce the flood peak at downstream locations and confine flooding to within the flood control system. To reduce the damages associated with controlled flooding, it is necessary to provide drainage works capable of emptying the flood storage area as quickly as possible after the cessation of main river flooding.

9.2.5 Flood Mitigation Reservoirs

In appropriate circumstances dams can be constructed to create reservoirs which control major flood flows by temporarily storing flood waters and releasing them at a safe flow rate. Such devices may be used to control floods arising from existing catchment conditions or to offset the impact of proposed land use changes.The degree of mitigation provided by a flood control reservoir depends on the combination of dam storage, spillway capacity and the pattern of flood inflows. The effect of storage is to decrease the flood peak without reducing the total volume of floodwater. The reduction of the flood peak is achieved at the expense of an increased duration of dam releases at lower rates. For dams equipped with gates or valves, these controls determine the rate of release and the degree of downstream mitigation. Complementary land use controls need to be enforced to prevent unsafe development and encroachment on the downstream floodplain.

9.3 FLOOD CONTROL ON RIVER SABARMATI

The Sabarmati River, which passes through the center of Ahmedabad, has been subjected to abuse owing to the fast pace of urban and industrial growth of the city [124]. Though it is a major source of water for the city and despite the building of a major barrage to retain water, except for a few months during the monsoon the river is dry. Sewage contaminated storm water outfalls and the dumping of industrial waste pose a major health and environmental hazard. The slums located along the riverbed also pose a major impediment to efficient management of monsoon floods in the river. Sabarmati River Front Development Corporation Ltd. (SRFDCL) has been formed to survey and prepare a comprehensive proposal for the development and flood mitigation.

9.3.1 Physical Features of River

- The river runs a meandering course of about 9 km from Subhash Bridge up to the Vasna Barrage through the city with an average width varying from 340 to 600 m.

- On observing the alignment of the river, there are two meandering loops. Wherever the river has meandered or turned its course, the river gorge has widened due to scouring. This is evident at Gaikwad Haveli and at Wadaj.
- The average reduced levels (RL) of the riverbed at Subhash bridge and Vasna Barrage are 39.2 m and 37.4 m respectively, the slope of the river is 1:5000. The height of the banks ranges from 4 to 9 m.
- A negative slope is observed from Sardar Bridge to Vasna Barrage.
- The edge is not clearly defined by embankments or retaining walls at most places. The river edge gently slopes down to the riverbed at several places, which have vegetation and have been encroached by slum settlements.
- The RL of top of gate of Vasna Barrage is 41.756 m. Filling Vasna Barrage up to these level results in flooding of the nearby areas in monsoons.

9.3.2 River Hydraulics

The impact of building embankments and reclaiming land along the riverfront on the dynamics of the river, scouring of the riverbed and on the stability of bridges was analyzed. Various heights of embankments and various waterway widths were taken into consideration to arrive at the proposed design. The variable parameters were the width of the waterway (250, 275 and 300 m) and the intensity of the flood (4, 5 and 7.5 lakh cusecs). In determining these parameters, following data was considered:

- The linear waterway required for bridges on the Sabarmati is 176 m.
- Subhash Bridge, Gandhi Bridge, Nehru Bridge and Sardar Bridge are all designed for an estimated flood of 4 lakh cusecs. Ellis Bridge is designed for an estimated flood of 5 lakh cusecs.
- The flood observed in 1973, prior to the construction of the Dharoi Dam was estimated at being 5 lakh cusecs.

The estimation of HFLs for a 5 lakh cusecs flood, analysis of required embankment heights and existing riverbank levels showed that, of the three waterway widths of 250, 275 and 300 m, a width of 275 m was optimal to achieve the objectives of the design.

Table-1 presents the data for the HFL in relation to bridge levels in the case of a 5 lakh cusecs flood. This indicates that in the case of a 5 lakh cusec flood, in the natural condition, the HFL is higher than the existing riverbanks in almost all sections of the river. The HFL for a 5 lakh cusec flood, with the proposed embankments and a waterway width of 275 m, is lower than that for the natural waterway by nearly 1.5 to 2.5 m. The level of the top of the proposed embankment is 0.6 m above the HFL of 5 lakh cusecs flood through out the stretch. The embankments would prevent flooding along the length of the river from Subhash Bridge to Vasna Barrage and the HFL will be lower than the soffits of all the bridges.

Table-1 HFLs for a 5 Lakh Cusecs Flood

Bridge	Bridge Levels (m)		HFLs (m)	
	Top of Bridge	Soffit of Bridge	Natural Condition	275 m Water-way
Sardar Bridge	48.520	46.225	49.14	46.95
Ellis Bridge	50.655	49.015	49.46	47.50
Nehru Bridge	52.130	49.114	49.63	47.73
Gandhi Bridge	50.450	48.257	50.28	48.41
Subhash Bridge	55.500	52.920	51.03	49.61

9.3.3 Water Retention

With the construction of the proposed embankments, it will be possible to retain water up to the top of the Vasna Barrage, the level of which is 41.7 m. At present it is not possible to do this since the riverbanks in southern Ahmedabad are lower than the top of the Vasna Barrage.

At present, water retained upstream of the Vasna Barrage is released into the Fatehwadi Canal for irrigating the Fatehwadi Command Area. If water is to be retained through out the year, up stream of the Vasna Barrage, it is imperative that an alternative way of irrigating the Command Area be identified. It is proposed that, throughout the year the depth of water at Subhash Bridge should be at least 1 m. To ensure this, instead of using the water retained by Vasna Barrage, the requirement of irrigating the Command Area may be met hrough various options available for the replenishing water such as from Narmada Main Canal, Dharoi Dam.

9.3.4 Embankments - Structural Aspects

The four techniques of building embankments are :

1) Reinforced Earth Panel Technology,
2) Geo-grid and Pre-cast Block Technology,
3) Pre-stressed Soil Anchor Technology and
4) Conventional RCC Retaining Wall Technology.

The two most popular choices for retaining earth on embankments are that of Reinforced Earth and Conventional RCC Retaining Walls. Out of the two recent trend has been to use Reinforced Earth Panel Technology for constructing embankments since it is found to be most cost effective.

9.3.5 Reinforced Earth Panel Retaining Walls

Reinforced earth is a composite material formed by embedding reinforcements in soil fill at regular intervals. The interlacing of compacted soil and reinforcements develops friction at their points of contact and forms a permanent bond between the two. The most common application of this technology is in the construction of retaining walls, wherein the reinforcement is best provided in the form of galvanized steel strips. The soil thus reinforced is provided with a skin of facing elements usually pre-cast concrete panels so as to facilitate soil confinement with a vertical face. However, currently the project envisages construction of Retaining walls with or without counterforts depending on the height and contours of the river bank from Subhash Bridge to Vasana Barrage. The height of the wall varies from 5.75 m to 7 m. Analysis and design has been carried out for seismic forces.

9.3.5.1 Basic components of reinforced earth walls

Reinforced earth wall (**Fig. 9.1**) is a composite engineered `mass' consisting of compacted soil, horizontal layers of reinforcement as metal strip rods or geotextile strips and sheets, or wire grids and a form of facing to prevent erosion of the soil. There is little difference in reinforcing soil or reinforcing concrete-both materials use reinforcement to carry the tension stresses developed by the applied loads. Bond stresses resist pullout in concrete and soil uses friction stresses developed based on the angle of friction between soil and reinforcement. The three basic components of a Reinforced Earth Wall are Earth, Reinforcing strips and facing panel.

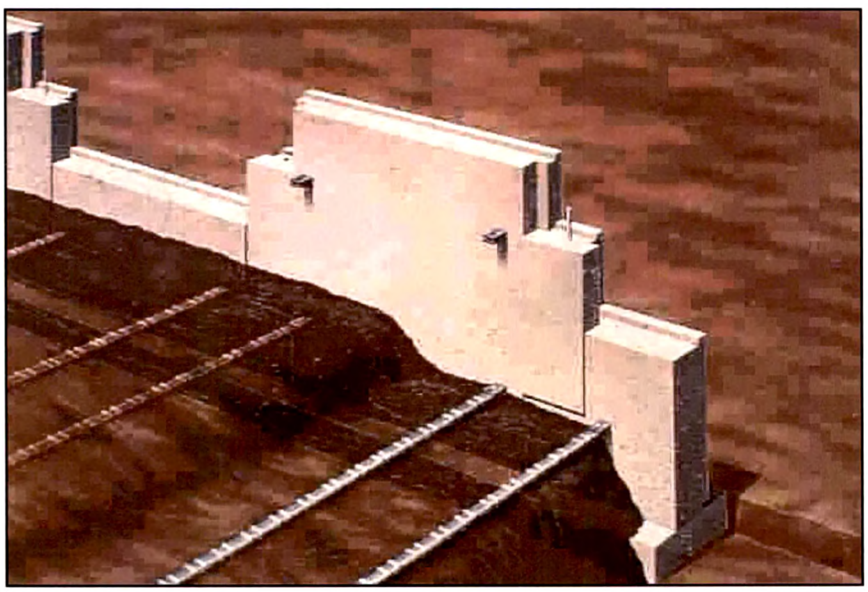

Fig. 9.1 Reinforced Earth Retaining Wall

9.3.5.2 Behavior of reinforced earth walls

The first stage of analysis of a structure of this type consists in designing the external stability of the reinforced block. Measurements taken in several structures have shown that, although it is composed of a flexible material that can carry major settlement without any appreciable disorder, the block can be initially considered for calculation purpose – as not on deform. The results obtained with this simplification have been sufficiently close to recorded observations. The choice of the type, number and distribution of reinforcing elements is called internal design. In order to make this choice, it is necessary to know the distribution of the loads along the reinforcing layers and the mechanism of interaction between them and soil. In this context, the properties of the surface of reinforcing strips and the expanding nature of the soil can be of particular importance. Measurements taken on actual structures and on small scale models and finite elements calculations have shown the tensile force in a reinforcing element reaches a maximum at a certain distance from the facing unit. The line (on cross section of a structure) formed by the points where the tensile force reaches a maximum is called the line of maximum tension. This line separates two zones in the structure: one near the facing unit, called the "active zone", and the other the resistant zone.

9.3.6 Counterfort Retaining Walls

Retaining walls over 6 metres in height are usually made of the counterfort type. The various components of such a wall are shown in the **Fig. 9.2.**

9.3.6.1 Upright slab

The upright slab is designed as a continuous slab spanning horizontally on the counterforts and subjected to lateral earth pressure. Let the lateral, horizontal pressure intensity at the bottom of the upright slab be p Newton per square metre. Consider the bottom one metre deep strip of the upright slab. If the spacing of counter forts be l metres centre to centre then the maximum bending moment for the upright slab strip = $pl^2 / 12$. The thickness required to suit this bending moment may now be computed. This slab is usually built of the same thickness. The steel runs horizontally, its requirement being away from the earth side at sections mid-way between the counter forts and near the earth side at the sections on the counter forts. The slab is also be provided with distribution steel at not less than 0.15 % of the gross area of the section, when M.S. bars are used and 0.12% of the gross area of the section when tor steel is used.

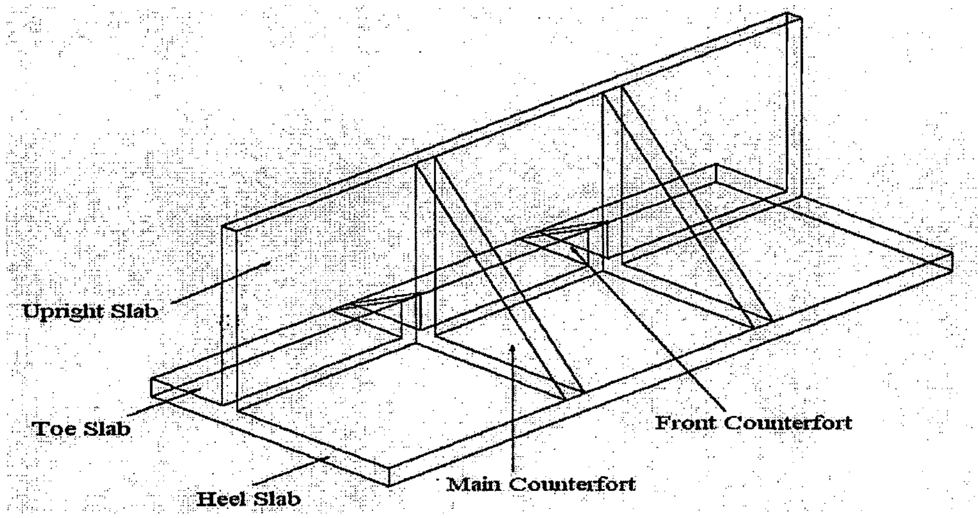

Fig. 9.2 Perspective View of Counterfort Retaining Wall

9.3.6.2 Base slab

The width of the base slab may be made 0.6 H to 0.7 H where H is the overall height of the retaining wall. The base slab consists of the toe slab and the heel slab. The toe projection is usually one fourth of the total width of the base slab.

Thickness of the base slab may be taken not less than the following, in order it may not be found unsafe from B.M. and S.F. considerations

$$D = 41.7 l \sqrt{h} \quad \text{to} \quad D = 20\, lh$$

where D = thickness of the base slab in mm, l = spacing of counter forts in meter, h = Overall height of wall in meter. If the soil is surcharged at angle α, increase h by 0.7 m. If the soil is super loaded, increase h by Super load intensity/ Wt. per unit volume of the soil.

9.3.6.3 Heel Slab

The heel slab is designed as a continuous horizontal slab with the counterforts as the supports. The slab is designed as a continuous slab consisting of continuous strips parallel to the wall. Each strip is uniformly loaded, but the loading on the various strips varies from a maximum at the heel edge to a minimum near the wall. The loading on a strip of heel slab will consist of the following (**Fig. 9.3**):

(a) Dead load of the strip.

(b) Weight of the earth above the strip.

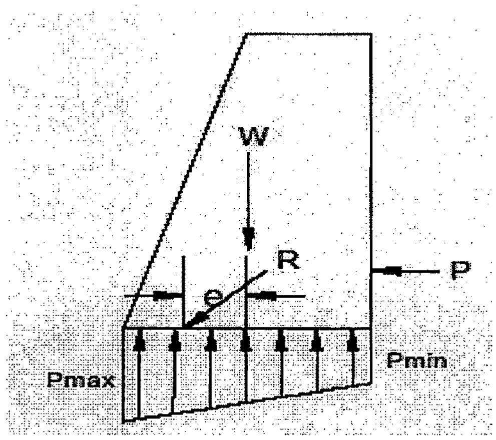

Fig. 9.3 Pressure Distribution on Wall

(c) Vertical component of lateral pressure in the case of earth surcharged at an angle. If the surcharge angle is α, then the intensity of vertical component of lateral pressure = cp wh' sin tan Φ

where cp = cos x cos – $\sqrt{\cos^2\alpha - \cos^2\Phi}$ / (cos + $\sqrt{\cos^2\alpha - \cos^2\Phi}$)
h' = height of earth above the strip, and φ = angle of repose.

(d) Super load intensity acting on the retained soil, if any

(e) Upward soil pressure.

The net load on the heel slab will be a downward load. If the net load be Q per unit area near the heel end, then consider a one metre wide strip near the heel end. The maximum bending moment for the strip = $Ql^2 / 12$. The moment will be a sagging moment at sections midway between the counterforts and will be a hogging moment at the sections over the supports.

9.3.6.4 Toe slab

The design of the toe slab depends upon whether the toe slab is allowed to remain a cantilever or it is made to act as a continuous slab by providing front counter forts. When the front counter forts are not provided, the toe slab is designed as a cantilever slab subjected to upward soil reaction. But if a front counter fort be provided, then the toe slab is designed as a continuous slab with the front counter forts as the supports.

9.3.6.5 Counterforts

The counterfort retaining wall may have main counter forts or main counter forts and front counter forts. Counterforts are spaced from 3 metres to 3.50 metres. This spacing may also be taken at one-third the height of the wall to half the height of the wall. The spacing may also be computed as the spacing for which the maximum bending moment for the upright slab requires an overall thickness of 300 mm. The Main Counterforts are designed as vertical cantilevers held in position by the base slab. The loading on these counter forts is due to the lateral earth pressure acting on the upright slab.

9.3.7 Design Of Retaining Wall For Seismic Conditions

Stem height : 5.75 m

Assumed S.B.C: 25 t/m^2

Grade of concrete: M 250

Tensile stresses in steel : 2660kg/cm^2

Stresses in concrete : 111.0 kg/cm^2

A. Active Earth Pressure

phi = 30.0

delta = 20.0

alfa = 3.979

i = 0.0

For calculating the active earth pressure on substructures Coulomb's theory is followed. ka = 0.3269

B. Forces due to Active Earth Pressure

Horizontal force due to Active earth pressure kah = 0.327

P1 = 0.327 * 2.00 * 0.5 * 6.35 * 6.35 = 13.18 t is acting at h/3 = 2.117 m.

Moment due to Horizontal Active earth pressure Ml = 27.90 t.m

C. Forces due to live load surcharge

P2 = 0.327 * 0.6 * 2.00 * 6.35 = 2.491 t

Moment at base due to live load surcharge M2 = 2.491 * 0.5 * 6.350
= 7.909 t.m.

D. Forces due Earth Pressure in Seismic Condition

Horizontal Coefficient of active earth pressure kahs = 0.057

P3 = 0.057*2.000*0.5*6.350*6.350 = 2.30 t is acting at h/2 = 3.175 rn.

Moment due to Horizontal Active earth pressure M3 = 7.30 t.m

Forces due to live load surcharge P4 = 0.057 * 0.6 * 2 * 6.35 = 0.434 t

Moment at base due to live load surcharge M4 = 0.434 x 2/3 x 6.350
= 1.839 t.m

Total Moment about toe M = Ml + M2 + M3 + M4 = 44.95 t.m

The wall is then checked for factor of safety against overturning and sliding for these forces and is found safe.

9.3.8 Design Of Diaphragm Wall

The embankments provided on the extreme edge of the bank, will be followed by walkways to be cast on reclaimed land (Fig.9.4). These walkways will finally terminate with a diaphragm wall holding the water for the depth of the river. The structural design for the retaining wall, slab cast on PCC over reclaimed earth and the diaphragm wall to be constructed at the edge of the walkway below the riverbed level, should be detailed on the entire belt from the water edge to the embankments for reclaimed earth.The height of the diaphragm wall is determined from the scour depth which has been calculated as 7.54m for a 5 lakh cusecs flood plus a requisite grip length of 2 m, bringing the depth required to 9.54 m.

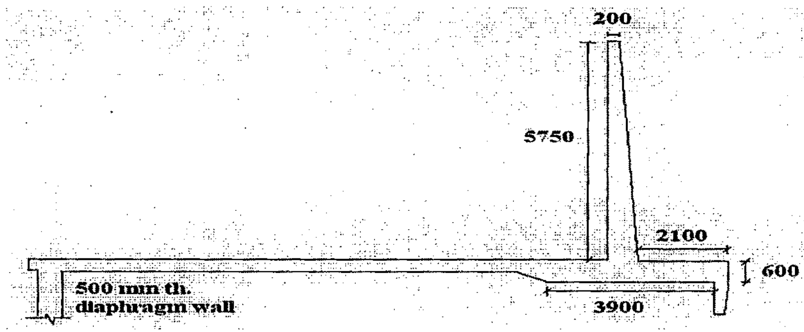

Fig. 9.4. Retaining Wall and Diaphragm Wall

9.4 FLOOD CONTROL ON RIVER TAPI

In situations when the inflow of waters during the monsoon exceed outflow without fail every year, construction of a dam becomes an inevitable decision though it may be opposed by the growing environment lobby. The Ukai dam in Surat was constructed with the sole purpose of protecting the city from floods. The 2006 flood has proved otherwise and it becomes imperative to learn from the experience how structural aspects alone cannot prevent a disaster. Related aspects have been discussed in the following paragraphs.

9.4.1 Encroachment of the River

The obstruction of the releasing of flood water is blamed on the slums but not on the town planning and the encroachment of the river basin by the urban builders with utter disregard to the environment and ecology. The narrowing of the Tapi river is revealing one. 40 years back it could carry 10 lakhs cusec of water. It has been reduced to 3.5 lakhs cusec. After the flood it can not accept more than 3 lakhs which can be further reduced if there is high tide to 2.5 lakhs. The general width of Tapi is 600 meters which is 400 meters at Adajan where the river has been encroached by the builders.

9.4.2 Purpose of the Dam – Flood Control or Reservoir

When Ukai dam was constructed, there was no Hazira Complex. The Hazira Industrial complex raised the demand by 2 to 3 meters, reducing the releasing of water of Tapi to the sea. Thus it had been forgotten that Ukai was meant to be a flood control device and not a reservoir. As Surat expanded, power and irrigation demands compelled authorities to start using it as a dam to store all the rainwater that flowed in. The level to be maintained in the dam before the inflow starts during monsoon was always a matter of contention.

There was hardly any excessive rainfall in the period preceding the deluge. The level of Tapi started rising after the Irrigation Department started releasing 8 to 10 lakh cusecs of water from the upstream Ukai dam as against the normal outflow of 6 lakh cusecs. Soon, the swirling Tapti inundated the fastest-growing town of Gujarat. This was more serious than the 1998 deluge, when release of only 6.73 lakh cusecs of water had caused the worst-ever flood in a quarter century. Thus the magnitude of the catastrophe brought in by the release of 8 lakh cusecs (50 per cent extra water is obvious). Apparently, a natural calamity was aggravated due to indiscreet proliferation in spite of the presence of a major structural advantage in terms of the dam. The Irrigation Department says it was forced to release water in unprecedented quantity because Ukai dam was facing grave danger, having already crossed the full reservoir level of 345 feet.

Thus the decision of whether to have a controlled flood by releasing the water or to face total devastation if the dam failed was obviously not too difficult to take.

9.5 CLOSURE

- Building of embankments and modification of the waterway eliminates the hazard of floods.
- Reinforced Earth Panel Technology though proved to be cost effective for constructing embankments, Reinforced Concrete Retaining walls have been preferred in major works due to the greater reliability for retaining earth.
- The fundamental objective of the design should be to ensure that the building of the embankments and narrowing of the waterway does not in any way raise the high flood level beyond that in the present condition of the river. This will ensure flood control in the low-lying areas.
- Appropriate development of the riverfront can turn the river into a major asset, with the improvement of quality of environment and can raise the

efficiency of the infrastructure of the city with promenades, public utilities and commercial areas.

- However non-structural aspects which need to be mentioned in any flood control proposal, such as, scouring depth and silting, will definitely impact the embankment efficiency.
- Drainage of flood water either by gravity or gates from the land that is protected by these very embankments, should also be addressed. In the SRFDCL proposal there is a mention of expanding the existing pipeline system for flood drainage. But the retaining embankments will be a major component for consideration.
- Bypass floodways and Flood retarding basins have not been considered in the comprehensive plan. These will definitely be required in case of high flood level situations as in case of the recent floods at Surat when about 2.75 lakh cusecs of water was released from upstream.
- Regulation regarding land use and its management of the low lying areas has not been put in place. Ahmedabad was fortunate enough to have been saved from the impending flood. This is the one single cause of the disaster that Surat has faced due to the frequent flooding of Tapi and more so in the devastation caused in August, 2006.
- Land use zoning may provide the most effective and least costly solution to the problems of disaster management for floods. This requires the restriction of agricultural development or urban settlement in locations which are particularly susceptible to flooding. Surat faces the fury of floods due to gross negligence in regulating haphazard and unplanned growth and urbanization of the low lying areas on both the banks of Tapi.
- Thus disaster response alone is not sufficient as it yields only temporary results at a very high cost. Prevention and mitigation contribute to lasting improvement in safety and are essential to integrated disaster management.