Chapter-6
Structure and Layout

6.1 General

The Polavaram - Vijayawada link canal will be a component of the Polavaram project proposed by the Government of Andhra Pradesh. The link canal will take-off from the right flank of Polavaram project. Designs for the head works have not, therefore been taken-up by NWDA. The alignment of the link canal is proposed to be the same as that of the Right Main Canal of Polavaram project as proposed by the State Government. However, the design discharge of the link canal is slightly different from that of the Right Main Canal of Polavaram project. This is mainly due to the additional quantity of water that is proposed to be transferred from Godavari to Krishna through the link canal and the variation in the water requirement for en route irrigation as worked out by NWDA and the State Government.

In view of the above, only a brief description of the design features of the head works of the Polavaram project is given here. The design features of the link canal, however, are presented in detail.

6.2 Structure, Layout and Design Features of the Head Works

6.2.1 Location of the Head Works

The proposed dam site is located near Polavaram village in West Godavari district of Andhra Pradesh where the river emerges out of the last range of the Eastern Ghats and enters the plains. The river, before it arrives at Polavaram site, passes through deep gorges of Papi hill range where the width of river is about 300 m. At Polavaram, the river width is about 1500 m. At the dam site the river bed is flat and entirely covered by alluvial sands. The slope of the river from Polavaram towards downstream side is 0.2 m/km (i.e., 1 in 5000).

The narrow sections higher up in the interior of the hilly tract were considered to be not suitable for locating the dam since the off taking of canals from these reaches would be difficult and costly involving numerous

tunnels and deep cuttings for considerable length along rugged terrain. Alternatively, the small reach upstream of Polavaram has been considered suitable. There are several hillocks and spurs in the vicinity of the dam site selected. The various components of the head works, like the main dam, spillway and non-overflow masonry dam, could be located between the hillocks taking advantage of the layout of the hillocks.

6.2.2 Components of the Head Works

The head works consist of an earth-cum-rockfill dam across the main river with the spillway on the right flank. The non-overflow dam consisting of river sluices, power dam, navigation lock and head regulator is proposed on the left flank. Suitable earthen bunds are proposed in the saddles. One head regulator is proposed at a saddle on the right flank for the Right Main Canal

The earth-cum-rockfill dam in the main river course is 1600 m long with a maximum height of 50.32 m. The spillway is 754 m long and is provided with 37 gates of size 16 m X 16 m to pass a maximum flood of 1.02 lakh cumec. The maximum height of spillway is 57.90 m. Suitable approach and spill channels are provided.

The non-overflow dam is 560 m long situated on left flank. It will accommodate the river sluices and twelve turbines of 60 MW each. At the extreme left flank the navigation lock and the head regulator to discharge 250 cumec are provided.

The non-over flow dam is connected to the hill ‘f ‘ by means of a masonry wall in a saddle which forms a small subsidiary reservoir into which the lock and the head regulator open. Saddle dams connecting the hills f & e, e & z_1 and z_2 & z_3, are provided by earthen bunds. The saddle KL is closed by another earthen bund. Similarly the saddles E and F on the right flank are closed by two earthen bunds.

The head regulator on the right flank is designed for a discharge of 453 cumec. Approach and exit are provided for the regulator by grading the high ground on upstream.

6.2.3 Geology, Seismicity and Foundation

The flanks of the river at the dam site are dotted with spurs and hillocks necessitating construction of a number of saddle dams. The abutments are marked by the presence of back swamps forming prominent saddles. The bedrock is available at depths ranging from 31 to 46 m over total width of about 1020 m of river section at the dam site. However, depths of 46 to 82 m are indicated in the remaining 240 m stretch of river section. In view of large depth of excavation to reach hard rock at the dam site, which is more than 30 m deep, it is decided to have an earth-cum-rockfill dam in the riverbed. The spillway is proposed to be located in the right bank saddle, where the foundation rock of reasonably sound and fresh Khondalites would be available at relatively shallower depths. Geological examination of the river bed at the project site with the help of bore hole data revealed that the bed rock is available at greater depths at some sections even going up to 76 m, in the river portion.

Drilling of bore holes, evaluation of foundation and engineering properties of foundation materials have been done by Geological Survey of India.

The project area falls under Zone-III as per the Bureau of Indian Standards Code IS: 1893-1984 – "Criteria for earth quake resistant design of structures".

6.2.4 Design Flood and Sedimentation Studies

The Polavaram project is proposed to be located about 42 km upstream of Godavari Barrage at Dowlaiswaram, which was constructed during 1970's. In the case of Godavari Barrage, a maximum flood discharge of 0.915 lakh cumec (32.30 lakh cusec) at a 200 year return period had been adopted. As the catchment area between Polavaram and Dowlaiswaram is so small that additional flood discharge will be nominal, it has been decided by the State to use the flood data available at Dowlaiswaram for the years from 1904 to 1975. Flood values prior to 1904, i.e., from 1881 to 1903 were estimated for increasing the length of the flood flow series to 95 years (1881 to 1975). The extended flood flow series has been analysed using Gumbel's flood frequency analysis modified by Ven Te Chow to arrive at the flood flow values at various return periods. These are reproduced in Table 6.1.

Table 6.1
Probable floods with their return periods

Return period (years)	Probable flood (lakh cumec)
25	0.636
50	0.723
100	0.814
200	0.898
500	1.010
1000	1.094

As per CWC criteria on the design flood, storages more than 61.67 Mm^3 (50,000 Ac.ft.) have to be designed for the probable maximum flood or 1000 year return period flood whichever is higher. However, in view of the fact that the Polavaram project can be considered as a barrage for design flood purposes and also as the construction of upstream storages will reduce the flood intensity (the Polavaram project is the terminal reservoir on river Godavari), a design flood of 1.010 lakh cumec corresponding to 500 year return period is considered for spillway design.

For the study of sedimentation of the reservoir, CWC had suggested adoption of the rate of 595.31 m^3/ km^2/year (1.25 Ac.ft. / sq.mile / year) from free catchment area and taking 25% of intercepted catchment as contributing silt into free catchment area in the actual sedimentation analysis. While the above rate has been adopted for free catchment, in case of intercepted catchments (1) for projects with known capacities, the silt rate is taken as per Brune's curves, and (2) for projects with unknown capacities, 25% catchment is presumed as contributing the silt. Since the crest level of the spillway is 24.50 m and the gates are to be operated every year, the possibility of silting above this level near the head works is remote. The control levels proposed are given in Table 6.2.

Table 6.2
Control levels of Polavaram Reservoir

FRL	45.72 m	As per interstate agreements
Design flood discharge level	42.67 m	dated 2.4.1980
MDDL / LWL	41.15 m	
Crest level of spillway	24.50 m	
Sill level of penstocks	25.00 m	
Top of gates	40.50 m	
Sill level of right side head regulator	35.50 m	
Sill level of left side head regulator	37.00 m	
Maximum tail water level	30.48 m	
Minimum tail water level	13.64 m	

6.2.5 Free Board

A free board of 7.6 m over FRL is kept for the earth-cum-rockfill dam, based on the Seville's method, fixing the TBL at 53.32 m for earth dam portion. The free board provided for non-over flow and spillway sections is 6.10 m against 4.7 m obtained as per relevant IS codes.

6.2.6 Canal Off-take Arrangements

Both the flanks of the river at the head works consist of hillocks and spurs in continuation to the hill ranges embracing the reservoir. Hence, if the main canals are to be drawn directly from the reservoir, these need to be aligned along the curvilinear contours of the rough terrain making it prohibitively costly. To suit this terrain, a system of subsidiary reservoirs has been proposed for taking off the canals from the reservoir.

a) Left Flank Arrangement

As the left canal is conceived as an irrigation-cum-navigation canal, it starts with a lock located on the left side of the non-over flow power dam. Water diverted through this lock enters a small pond formed by constructing a masonry wall and then enters a subsidiary reservoir through an open cut. From this subsidiary reservoir, an irrigation-cum-navigation

canal takes-off and finds its way skirting along the hills into the Nelakota Ava subsidiary reservoir. The Left Main Canal takes-off from the Nelakota Ava subsidiary reservoir and the FSL of this canal is fixed at 40.54 m.

b) Right Flank Arrangement

The diversion of waters on right flank will be through a head sluice located in the saddle on the right of the spillway. From this sluice, water will first be let out into two subsidiary reservoirs formed by construction of saddle dams and connected by an open hill cut. From the second subsidiary reservoir, water will reach the approach cut to the tunnel, at the end of which a stilling basin is proposed. The Right Main Canal (Polavaram - Vijayawada link) takes-off from this stilling basin through a head regulator with FSL at 40.232 m.

6.2.7 Stability Analysis of the Earth dam

The stability analysis of the slopes of the dam has been done by the State Government on the final sections using Slip Circle Method confirming to the Bureau of Indian Standards code IS: 7894-1975. The seismic co-efficients adopted for analysis are 0.08 for horizontal and 0.04 for vertical, since the Polavaram dam site lies in Zone-III. Shear properties adopted in the stability analysis are based on the test results. The details are given in Table 6.3.

Table 6.3
Shear parameters considered for earth dam

Particulars	At OMC		At 100%		I.S. Classification
	C(kg/m^2)	ø	C(kg/m^2)	ø	
Hearting soil	6000	9^o	4000	5^o	CH
Rock-fill	-	-	0	40^o	
Sandy foundation	-	-	0	30^o	
Clay foundation	-	-	8500	7^o	

The reach-wise factors of safety obtained in the stability analysis are given in Table 6.4.

Table 6.4
Results of stability analysis for earth dam

Condition	Dam section (Chainage in m)			
	(0 to 400)	(400 to 1000)	(1000 to 1300)	(1300 to 1600)
Downstream steady seepage (normal)	1.650	2.025	2.026	1.652
Downstream steady seepage (earthquake)	0.957 (~ 1.0)	1.054	1.200	1.124
Upstream sudden draw down (normal)	1.747	2.208	2.135	1.707
Reservoir full (earthquake)	1.067	1.042	0.978 (~ 1.0)	1.093

The above factors of safety are satisfying the minimum factor of safety criteria given in the relevant IS codes.

6.2.8 Spillway

The spillway consists of a single straight ogee section with 37vents of 16 m x 16 m. The effective length of the spillway is 592 m and the over all length is 754 m. The crest level is kept at 24.50 m and a breast wall is provided above top of gate i.e. at 40.50 m. A sloping apron type energy dissipating arrangement is proposed for the first 17vents on the left side while the remaining 20 vents on the right side consist of roller buckets of radius 13.50 m. For the maximum section of spillway with foundation at -6.10 m, a slope of 2 to 3 on the upstream side and 1.25 to 1 on the downstream side were found necessary for the sake of stability. The bed width considered is 62.65 m. The stability analysis has been done for all the combinations of loads as stipulated in the Indian Standards code IS: 6512-1972 and compressive stresses obtained were found to be within the permissible working stresses.

6.2.9 Non-over flow Masonry Dam

The non-overflow section of length 560.0 m is located in the left flank saddle comprising non-over flow block of 30.0 m, river sluices block of 33.0 m, power block of 360.0 m, non-over flow block of 45.0 m, left canal head regulator of 60.0 m and navigation lock for a length of 32.0 m. The

top width of the non-over flow section is 9.40 m with upstream batter of 1 in 20 and downstream batter of 0.75 to 1.

6.2.10 Navigation Arrangements

The region through which the Polavaram - Vijayawada link canal passes through is fully developed in respect of communication facilities. National Highway-5 passes almost parallel to the link alignment and various state highways, district and other roads connect several towns and villages of the region with this highway. In view of this, navigation proposals have not been considered in the Polavaram - Vijayawada link canal project.

However, there is an age old navigation system existing in the Godavari river and the delta canals. Provision for necessary navigation locks in the Polavaram dam and appurtenant works is kept to facilitate navigation in the Godavari river from Bhadrachalam to Rajahmundry and then to Chennai via Godavari - Krishna delta canals and Buckingham canal. Modification of the existing navigation facilities in Krishna and Godavari delta canals (which run almost parallel to the Polavaram - Vijayawada link canal) is actively pursued by the State of Andhra Pradesh.

6.3 Design Features of Polavaram – Vijayawada Link Canal

6.3.1 Description of the Canal System

As already mentioned in Section 6.2.6, the Right Main Canal of Polavaram project (which is the same as the proposed Polavaram - Vijayawada link canal) takes-off from the stilling basin on the right flank of Polavaram project through a canal head regulator. The general topography of the area through which the Godavari (Polavaram) - Krishna (Vijayawada) link canal will pass is mostly plain with a few local high mounds and sporadic hills. In the initial reach of 57 km the canal runs in southern direction and then takes right turn and runs in south westerly direction up to RD 162 km. It again turns to the right and runs in northern direction up to 170 km. After this the canal runs in westerly direction up to RD 174 km where it joins the Budameru river upstream of an existing regulator near Velagaleru village. From here, the water will be diverted to river Krishna through the Budameru diversion channel. The alignment of link canal runs mostly in balanced depth of cutting and filling.

The canal will be lined with a bed slope of 1 in 20000. The canal is designed as a trapezoidal section with bottom corners rounded. The

velocity from head to tail ranges from 1.050 to 0.922 m/sec. The full supply depth is 4.9 m at the head. Sections of the canal at head and tail ends are 4.9 m X 68.50 m and 3.95 m X 68.5 m respectively. The canal capacity at head and tail will be 405.12 cumec and 279.53 cumec respectively. The canal has been designed for 1.1 times the peak discharge. A free board of 1.0 m is provided throughout the length of link canal.

The alignment of Godavari (Polavaram) - Krishna (Vijayawada) link canal is kept mostly same as that of Right Main Canal of Polavaram project.

6.3.2 Utilisation of Water Potential from the Streams Crossed by the Canal

Various streams and rivulets crossed by the Polavaram - Vijayawada link canal are not perennial. The yields are undependable and the streams are prone to flash floods. The possibility of providing additional storage on these streams is remote because of the nature of the topography and submersion of large tracts of cultivable lands. Possibility of balancing reservoirs en route is examined and found to be not feasible. In view of the above, it is found that the utilisation of water from these streams is not feasible.

6.3.3 Description of Soil Profile along the Canal Alignment

The details of sub-surface strata have been collected by the State Government by excavating open trial pits and auger holes at every 200 m interval along the entire length of canal alignment. The soils are ordinary gravel, loamy soil, etc. for the first 2 to 3 m depth on an average. Harder soils are met at depths ranging from 3 to 6 m.

6.3.4 Evaluation of the Design Parameters based on Samples Collected en route

The canal alignment generally runs in partial cutting and embankment. The soils available from cutting and adjoining borrow areas are found to be suitable for embankment purposes. When the canal runs in embankment higher than 8 m, the soils available in the adjoining fields are proposed for formation of the embankment.

6.3.5 Lining

100 mm thick CC (1:3:6) lining is proposed for both bed and sides throughout the length of the canal.

6.3.6 Transmission Losses

The transmission losses are assumed as 0.60 cumec per million sq.m. of wetted area as per Bureau of Indian Standards Code IS: 10430-1982.

6.3.7 Cut-off Statement

The cut-off statement showing the details of the discharges required for irrigation en route and transmission losses at each offtake point has been prepared for all the months of the year. The total transmission losses works out to 260 Mm^3.

6.3.8 Design Calculation for Adequacy of Canal Section

a) Formulae used

The canal sections for various reaches are designed using Manning's formula for velocity,

$V = (1/n)R^{2/3} S^{1/2}$, where

V = Velocity
n = Rugosity co-efficient
S = Bed slope
R = Hydraulic mean depth (A/P)
A = Area of cross section = $bd + d^2 (ø + \text{Cot } ø)$
P = Wetted perimeter = $b + 2d (ø + \text{Cot } ø)$
b = bed width
d = depth of water
Ø = Angle of the side slope

The critical velocity for the canals in Godavari delta and nearby region is given by $V_o = 0.391\ d^{0.55}$ (as per guidelines of CWC).

The Rugosity co-efficient for the lined canal is taken as 0.018; Side slopes of 1.5 horizontal to 1 vertical and bed slope of 1 in 20000 (except in the flumed sections where the bed slope is 1 in 14000) are taken.

b) Design of Canal Sections in Various Reaches

The peak discharge required at the head of the canal is worked out based on crop water requirement. The design discharge is considered to be greater of the following:

1) 1.1 times the peak discharge, and
2) 1.25 times the average discharge.

The design discharge at head thus calculated is 400.39 cumec, against the actual peak discharge of 363.99 cumec. Out of 363.99 cumec, 257.13 cumec form the diversion component into river Krishna. The remaining 106.85 cumec of water will be utilised for irrigating 139740 ha of CCA en route including lift schemes, and domestic and industrial water supply to the tune of 162 Mm^3 in the areas en route.

As the canal goes down from the reservoir, the discharge in the canal gets reduced at every off take point due to drawl of water to meet the requirement of en route command. This necessitates the reduction in canal section in order to effect economy. However, it is not feasible to change the canal section at every off take point. Hence, the canal is broadly divided into suitable hydraulic reaches and the sections are designed to carry the required discharge in that particular reach.

The entire canal is divided into 15 reaches based on the following considerations:

1) Below a major off take point
2) Where the discharge of canal falls by 10%.

The velocity allowed is in the range of 1.050 to 0.922 m/sec, the critical velocity ratio being 1.10. The full supply depth provided is 4.9 m in the head reaches and 3.95 m in the tail reaches. A free board of 1.0 m above FSL is provided throughout the length of the canal. The b/d ratio obtained at head is 13.98 whereas it is 17.34 in the tail reach.

The details of loss of head provided at different structures are given in Table 6.5.

Table 6.5
Details of head losses at different structures (in m)

Name of structure	Head loss
Bridges and super passages	0.015 m
Regulators	0.150 m
Aqueducts	0.060 m
Small CD works	Not provided

The total head loss due to structures is 3.42 m in the entire 174.0 km length of the canal.

c) Discharging Capacity of Budameru Diversion Channel

As per the designed hydraulic particulars of the Budameru Diversion Channel the flattest slope occurs in the reach between RD 8.30 and 9.70 km for which discharge capacity of the Budameru Diversion Channel (as per NW norms) has been checked and the details are furnished below:

I. Data

1. Bed width : 82.32 m (Constant throughout the length of BDC)
2. FSD : 3.494 m, say 3.5 m
3. Bed fall : 1/6400
4. Side slope : 2:1
5. Rugosity co-efficient (n): 0.018 (for lined canal)

II. Computations

$A = (82.32 + 96.32) \times 3.5 / 2 = 312.62\ m^2$
$P = 82.32 + (2 \times 7.83) = 97.98\ m$
$R = 3.19\ m$
$V = 1/0.018 \times 3.19^{2/3} \times (1/6400)^{1/2} = 1.504\ m/sec$
$Q = 470\ cumec$

Since the actual peak discharge of the Polavaram - Vijayawada link at its outfall into Budameru is 250.52 cumec, which is less than the discharging capacity of the Budameru Diversion Channel at its outfall reach, it could be concluded that the Budameru Diversion Channel can carry the required discharge in the other reaches also with steeper bed slope. During the periods of flood diversion of Budameru waters through the Budameru Diversion Channel, the transfer of Krishna through the Polavaram - Vijayawada link canal will be regulated according to requirement.

6.4 Cross Drainage works

As the link is aligned as a contour canal, it crosses several streams and minor rivers. It also crosses several roads, since the country it passes through is fairly developed and populated. The type of cross drainage work depends upon the catchment area of the stream and its bed level with reference to full supply level and bed level of the canal at the crossing. In general, aqueducts are proposed across major streams and under tunnels across small streams. Super passages are proposed when the bed level of the streams is much higher than the full supply level of the canal at the crossing. In view of the large size of the canal, syphons are avoided. One silt ejector is also proposed across the link canal at RD 2.07 km.

6.4.1 Details of Canal Structures

In the entire length of 174 km of the link canal, 67 cross drainage works are provided, which comprise of 8 aqueducts, 38 under tunnels and 21 super passages. The single lane and double lane bridges are also provided wherever necessary. There are 22 single lane bridges and 22 double lane bridges.

Bore holes data is collected at each major stream crossing for design of structure. It is found that availability of hard strata in the foundations is varying from structure to structure.

6.4.2 Computation of Maximum Flood Discharge

The formulae adopted for computing the maximum flood discharge in the streams and rivers crossing the canal are given in Table 6.6.

Table 6.6
Formulae for maximum flood discharge

Catchment area (km^2)	Flood discharge (cumec)
For < 2.6	$19.50A^{3/4}$
For 2.6 to 78	$16.70A^{3/4}$
For 78 to 1300	$14.75\ A^{3/4}$
For > 1300	$\frac{123.16\ A}{(A+10)^{1/2}}$

Note: 'A' is the catchment area of streams at the crossing of canal in km^2.

6.4.3 Percentage of Fluming Proposed

The canal is flumed at the site of structures like aqueducts, bridges and super passages with a view to minimise the cost of structure. At the site of aqueducts, the canal is flumed up to an extent of 50%. The percentage of fluming at bridges and super passages is about 10% to 15%.

6.4.4 Typical Hydraulic Design of CD Works

The typical hydraulic designs of (1) aqueduct across Ramileru at RD 122.35 km, (2) super passage across Kovvada Kalva at RD 6.625 km, and (3) under tunnel at RD 17.42 km have been done.

6.5 Cross Regulators and Bridges

Cross regulators are provided at regular interval in order to ensure effective water regulation. Regulators are provided whenever the discharge of the distributary/branch canal is about 10% or more that the main canal discharge. These are combined with bridges wherever possible to provide access to the nearby villages and also to minimise cost. Head loss of 0.15 m is provided at each regulator.

The Polavaram - Vijayawada link canal crosses NH - 5, state highways, major district roads and a number of village roads at various points. To facilitate free flow of traffic, double lane bridges and single lane bridges are proposed depending upon the type and importance of the road crossing. Bridges are provided at 3 km interval on an average duly diverting the intermediate cart tracks and village roads to the nearby proposed bridge. Road formation levels are fixed in such a way that the minimum required vertical clearance of 1.2 m above FSL of the canal is available. In all, there are 44 road bridges along the alignment of the link canal.

6.6 Escapes

Escapes are proposed especially to take care of the vulnerable embankment reaches to divert the canal flows into nearby streams in case of breach in embankment. The escapes are designed for 50% discharge of the parent canal in order to minimise the cost. In all, three escapes are provided along the alignment of the link canal.