OPTIMUM DESIGN OF ANCHOR BLOCK SUPPOTING PENSTOCK

DISSERTATION

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Jay P. Shah

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ACKNOWLEDGEMENT

It is my matter of great pleasure, that I am sumitting my thesis "Optimum Design of Anchor Block Supporting Penstock". This thesis is a part of my terminal curriculum. At this moment, I owe my deep sense of gratitude to my revered guide **Shri Sharad P. Purohit**, Sr. Lecturer, Civil Engineering Department, Nirma Institute of Technology, who has helped me throughout my presentation of the thesis. I was fortune to have a guide of such high academic standard who was always there to solve my problems and difficulties during my thesis work. I think without his academic and moral help, the thesis would not have been, what it is today.

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ABSTRACT

Anchor Blocks are the massive structure which supports the large diameter pipe. The massiveness of such blocks make them considerably costly and particularly in case of long penstocks where a number of such bends are needed, the total cost can form a substantial portion of the total penstock budget, so it is required to make optimized Anchor Block.

This thesis is an attempt to understand how to optimize the shape and size of Anchor Block by fulfilling all the requirements required to stabilize it. Analysis and Design of anchor block was carried out for five different types of bend, namely, vertical (concave & convex), horizontal and combined bends (concave & convex) at different location along the length of penstock having different location with optimized shape. Also parametric study was undertaken to understand the influence of different parameters on the shape of Anchor Block.

Software based on VB platform was also developed for user (any) to quickly analyze and design the anchor block. Software also, carry out structural reinforcement detailing for all types of anchor block. The results obtained from a developed software were validated for input data's from L & T, chhani, Baroda.

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1.1 Background

Anchor blocks, as their name indicates, are massive concrete blocks encasing the penstock pipe at intervals in order to anchor down the pipe to the ground securely. Such blocks are necessary at all horizontal and vertical bends of the penstock pipe. Besides the bends, anchor block are customarily provided on straight reaches, at intervals of 150 m or so. The anchor blocks tend to prevent movement of the penstocks due to steady or transient forces including expansion or contraction forces and water hammer pressures. They provide the necessary reaction to the dynamic forces at the bends. In general, the anchor blocks, by transmitting the penstock loads to the ground, provide the necessary degree of stability to the pipe assembly. The massiveness of such blocks makes them considerably costly and particularly in case of long penstocks where a number of such bends are needed, the total cost can form a substantial portion of the total penstock budget.

The anchor blocks may completely encase the pipe as in Figure 1b or can be constructed only up to the centre line of the pipe as in Figure 1a. However it is generally appreciated that procedure of Figure 1b is functionally better, as it increases the keying length as well as provides additional resistance against sliding. The foundation of the anchor block is provided on a serrated rock or soil surface to ensure proper key with the foundation. Many times anchor rods are grouted down into the sub – soil from the base to provide additional factor of safety.

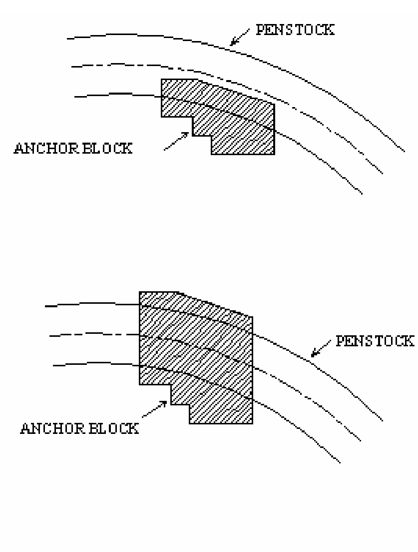


Figure 1.1 Different types of Anchor Block

1.2 Classification of Penstock Support

In order to reduce longitudinal stresses which may be caused on account of restrain on movements due to temperature variations and other causes, expansion joints may be provided in the pipe line at suitable points. Such expansion joints are generally provided on the down side of an anchor block and closest possible to it, preferably between the block and the pier or support. By consideration of restraint on movement, pipe lines can be classified into three categories. Pattern of stresses induced in the conduit will also be different for different categories. This will also influence the design of anchors and supports.

Rigid Type

There is no flexible joint in the pipe line and it is rigidly connected to the anchorages at the two ends of the grade. Intermediate supports if any, are also anchor type or else the pipe line is continuously supported. In such cases all movements will be completely prevented and significant longitudinal stresses may develop.

Rigid pipe lines can be installed if no great changes of temperature are expected; such as in the case of buried pipe lines.

Semi – Rigid Type

Penstock is divided in long segments which are connected by an expansion joint or flexible coupling. Implication of such an arrangement is that the flexible joint will accommodate all the movements in a segment. Therefore, each segment can be fixed only at one point and on rest of the supports full movement should be ensured. However, in any long segment of a pipe line some axial restraint may still develop on account of various factors.

Loose – Coupled Type

In this type of installation, expansion joints are provided in each section. Since in such an arrangement moment in each section will be unrestricted, practically no axial forces will develop. Penstocks with sleeve – type couplings are in this category. Such an arrangement will be feasible only in case of smaller dimensioned pipe lines which are buried. Large diameter pipes operating under high heads are never loose coupled type.

1.3 Method of Support

Generally two method of support are widely exersized in field, namely Burried or Embedded pipes and Exposed pipes. The advantages and disadvantages of the same are enlisted as shown in Table.

Type of Support	Description	Advantages	Disadvantages
Buried or embedded pipes	A penstock may be either buried or embedded under ground or exposed above the ground surface and supported on piers as shown in Figure 2. The buried pipes are supported on soil in a trench at a depth of 1 m to 1.5 m and after placement, the trench is backfilled. For buried pipes the general topography of the land should be gently sloping and of loose material.	• Continuity of support given by soil so that the system becomes strong structurally. • Protection of the pipe against temperature fluctuations with the help of small overburden. • Conservation of natural landscape. • Protection from landslides, storms and man – made violence.	• Difficulty in inspection of faults • Possibilities of sliding in steep slopes • Difficulty in maintenance • Greater expenses for large diameter penstocks in rocky soil
Exposed pipes	The pipes may also be constructed above the ground surface supported by piers or saddles. According to USBR (United States Bureau of Reclamation) definition, the non – embedded penstocks include	• Ease in inspection in faults and maintenance. • Economy in rocky terrain and large diameters. • Stability ensured	• Direct exposure to weather effects. • Development of longitudinal stresses on account of supports and

	supported penstocks exposed to view and penstocks encased in a protective layer of concrete in which the concrete is not considered to contribute to structural strength.	with anchorages.	anchorages, thereby necessitating expansion joints.

Table 1.1 Advantages and Disadvantages of different types of support used for penstock

Buried pipelines should be ideally being at least 750 mm below ground level specially when heavy vehicle are likely to cross it. Burying a pipe line removes the biggest eyesore of a hydro scheme and greatly reduces its visual impact. However, it is vital to ensure a buried penstock is properly and meticulously installed because any subsequent problems such as leaks are much harder to detect and rectify.

Where the nature of the ground renders burying the penstock impossible there is sometimes no option but to run the line above the ground, in which case piers, anchors and thrust blocks will be needed to counteract the forces which can cause undesired pipeline movement.

The different support structures can usually be built of rubble masonry or plain concrete. Anchor blocks may need steel reinforcement and triangulated steel frames are sometimes used for support piers.

1.4 Types of Anchor Block:

When the types of support of pipe is exposed type then we have to go for good anchoring because there is no continuous support is provided as in embedded pipes. There are two types of support when the pipe is of exposed type enlisted in Table 2.

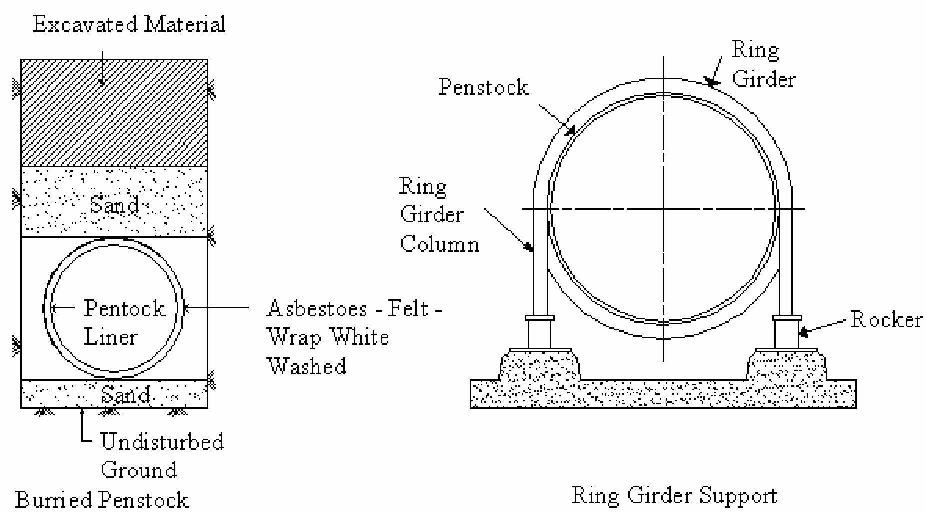


Figure 2 Methods of Supporting Penstock

Table 2 Location of different types of Anchor Block

Sr. no	Type	Description	Spacing
1	Open type	In this type of anchor the penstock is anchored to the concrete by rings as shown in Figure 3.	For penstocks freely supported above ground surface or in open tunnel over the suitable intermediate supports, anchors shall be provided at all bends and at intermediate points in long tangents and where the distance between any two bends requiring anchors exceeds 150, normally (up to 200 m in special locations).
2	Closed type	In this type of anchor the pipe is embedded in concrete as shown in Figure 4.	For buried penstocks, anchor blocks shall be provided at horizontal bends with large deflection angles which will produce forces not exceeding the frictional and compressive resistance of soil, at vertical bends at summits and at bends adjacent to power house or pumping plant.

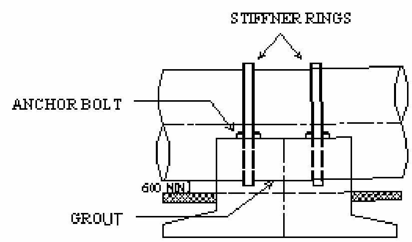


Figure 1.3 TYPICAL OPEN TYPE ANCHOR BLOCK

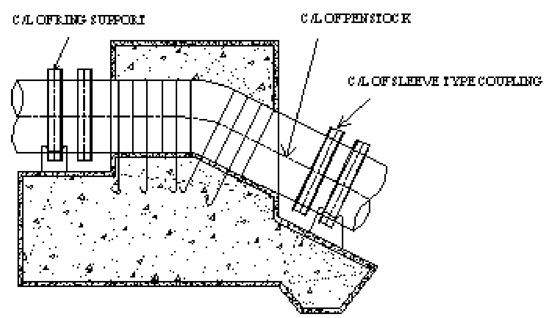


Figure 1.4 BLOCK WITH SLEEVE TYPE COUPLING

1.6 Design of Anchor Block:

Designing of Anchor Block is carried out for the four different conditions listed below and among four for the worst condition Anchor Block is to be design.

1.6.1 Various condition of design:

1) Pipe flowing at design discharge – expanding condition (temperature rise).
2) Pipe flowing at design discharge – contracting condition (temperature fall).
3) Pipe empty – expanding condition.
4) Pipe empty – contracting condition.

1.6.2 Design Criteria:

Designing an Anchor Block for the worst condition must have to check for the different criteria listed below. So the Shape of the Anchor Block is such that it must be fulfill the different criteria listed below:

- The foundation of anchor blocks shall be designed so that the maximum pressure on the foundation shall not exceed the allowable bearing pressure of the soil, determined as specified in IS : 1904 – 1978 which shall be confirmed by tests. The permissible bearing capacity may be increased in accordance with IS : 1893 – 1975 for seismic conditions.
- When the profile is sloping, the safe bearing capacity shall be reduced to take into account the decrease due to non – normality of resultant to the surface in accordance with IS : 6403 – 1971. The angle set up by resultant with ground shall not be less than 30° for stability of soil below anchor.
- Anchor blocks shall be designed safe against sliding on foundation. The sliding friction factor computed by dividing the total horizontal forces by total vertical forces shall be less than that given in Table 3:

Surface	Sliding Factor
Concrete on rock	0.50
Concrete on gravel	0.40
Concrete on sand	0.33
Concrete on clayey soil	0.25

Table 1.3 Sliding Factor for different surfaces

Material of pipe and piers	Co - efficient
Steel on concrete (cradle supports)	0.60
Steel on concrete with asphalt roofing paper in between	0.50
Steel on steel, rusty plates	0.50
Steel on steel, greased plates	0.25
Steel on steel with two layers of graphite service sheets in between	0.25
Rockers supports, deteriorated	0.15
Roller supports, deteriorated	0.10
Concrete on concrete	0.75

Tabel 1.4 Co – efficient of pipe on piers

- In case the anchor blocks rests on solid rock, without any weak planes capable of sliding, the sliding factor shall be designed for 0.75. Where however, weak seams or joints along which sliding may be apprehended in the rock below, the stability should be checked by the following shear friction formula:

$$\text{Shear friction factor} = \mu'\Sigma V' + \tau a''/\Sigma T$$

- The design of the anchor blocks shall be such that the resultant of all the forces falls within the kern of the base. For anchor blocks with stepped bottom the designs shall be made so that the resultant falls within the kern of the projection of the anchor base on a plane perpendicular to the resultant. Under seismic conditions, however tension up to 0.2 N/mm^2 may be permitted. The bearing pressure should be checked neglecting area under tension.

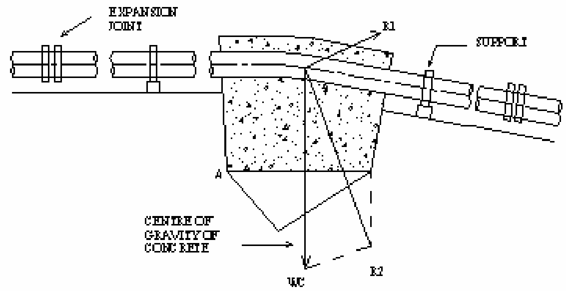


Figure 1.5 STABILITY OF ANCHOR BLOCK WITH STEEPED FOUNDATION

1.7 Rigidity of Connection and Support

In order to minimize the possibility of excessive longitudinal stress development, the pipe may need certain flexible joints besides rigid joints.

Flexible couplings and expansion joints facilitate the removal of adjacent pipe section and a speedy replacement. The main functions of an expansion joint are:

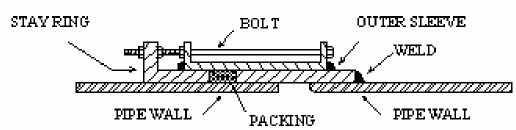


Figure 1.6 A TYPICAL EXPANSION JOINT

- To reduce the temperature stresses in the pipe or eliminate them except for small forces due to friction at the gland and water pressure on the end of the pipe shell.
- To act as a make-up joint because it is easily collapsible and is the last section to be placed between anchors.
- To permit construction from a number of locations at the same time rather than from only one location.

1.8 Basic Terminology

Anchor block:

Anchor blocks are large structures which represent the fixed points along a penstock, restraining all movements by anchoring the penstock to the ground.

Thrust block:

Thrust block is used to oppose a specific force, for example at a bend or contraction

Piers:

Piers are provided between two Anchor Blocks. They are used primarily to carry the weight of the pipes and enclosed water.

Expansion joint:

In order to minimize the possibility of excessive longitudinal stress development. It facilitates the removal of adjacent pipe section and a speedy replacement.

Penstock:

Penstock is one type large diameter pipes. Generally it is used to generate energy so usually diameters of such pipes are large. It may be made up of Steel or R.C.C.

1.9 Scope of Work:

As discussed in previous section analysis of Anchor Block is carried out for the four different conditions and for the worst condition Anchor Block is to be designed. Design of Anchor Block required four different checks shown in previous section.

Analysis of Anchor Block

- Computation of Forces manually
- Analysis under various load combination

Design of Anchor Block

- Design of concave type bends with and without expansion joint.
- Design of convex type bends with and without expansion joint.
- Design of horizontal bend with and without expansion joint.
- Design of combined bend with and without expansion joint.

Optimum design of Anchor Block

As such Anchor Block is large volume of concrete so we have to go for optimum size and shape of Anchor Block which fulfill all four requirements shown in previous section.

Reinforcement Detailing of Anchor Block

Computer Programming

- Excel based programs to Design Anchor Block.
- VB 6 based programs for Optimum Design of Anchor Block.

2.1. General

Literature survey is essential to review the work done in the area of designing and optimizing Anchor Block. To take up the specific need to perform the design and optimization, the literature like technical papers and books need to be referred. The prime important in the review was to understand the analysis, design and optimizing the anchor block.

2.2 Requirement of Anchor Block

Anchor Blocks are required to hold the Penstock without allowing any movement in it, considering waterhammer and earthquake forces. According to **M. M. Dandekar and K. N. Sharma [1]** gives that, Anchor Blocks are required to hold pipe line at intervals along its length in order to:

a) Prevent the pipe line sliding down the hill,
b) Control the direction of expansion,
c) Resist the unbalanced hydrostatic forces at a change of direction of the pipe line, and
d) Prevent movement of the pipe line on account of vibration or water hammer pressures within permissible limits.

2.3 Location of Anchor Block

Actually Anchor Blocks are required when the pipe changes its direction due to which large amount of forces were generated. So, according to **Thrust Blocking [6]** and **Thrust Block Instruction [4]** both fixed and semi – rigid penstocks are secured in place at points by anchor blocks. Anchorages represent the fixed supports of the penstock and are located at either vertical or horizontal bends in the line. There are three general types of anchorages at

- a concave vertical bend,
- a convex vertical bend, and
- Simple intermediate anchorage.

2.4 Stability of Anchor Block

As such Anchor Block is a supporting structure of Penstock, anchor block must be check for different criteria given by **M. M Dandekar and K. N. Sharma [1].** Anchor Block must fulfill all four requirements listed below within their specified limit:

1) There is to be no sliding at any section in the anchor block.
2) There is to be no overturning or rotation of the anchor block.
3) There is to be no tension in any part of the concrete of the block.
4) There is to be no crushing or failure due to compression in the block or at the foundation.

All the forces on the anchor block can be resolved into horizontal and vertical components giving sum total forces in horizontal and vertical direction acting at the point of intersection of the centre lines of the pipe u/s and d/s of the anchor block. These forces, denoted ΣH and ΣV respectively can be termed as active forces. Let the self – weight of the anchor be W_{blk} and weight of water and pipe supported by the anchor be W_{p+w}

For sliding stability

$$\Sigma H \leq \mu(-\Sigma V + W_{blk} + W_{p+w})$$

where μ is the coefficient of friction for which an average value of 0.5 can be presumed.

Overturning criterion is automatically fulfilled if the third criterion of 'no tension' at the base is fulfilled. For this the net resultant of $(-\Sigma V + W_{blk} + W_{p+w})$ and ΣH must lie within the middle third of the base.

For no crushing criterion, the maximum compressive stress at any horizontal section must be within safe limits. Particularly for foundation, the load transmitted to the foundation must be within the safe bearing capacity limit of the foundation material.

The shape and dimensions of the anchor block of given width should be so adjusted that the resultant of forces and the dead weight of the anchor pass through the middle third of the base of the block for no tension in masonry, and the maximum pressure transmitted to the foundation is within the allowable bearing pressure of foundation.

The downstream face of the anchor block is inclined for reasons of stability and the base is frequently stepped for economical reasons. Flat and stepped bases may be horizontal or built with a counter slope. The safety against sliding is to be tested. Safe resistance against sliding should be ensured and the factor of safety should be 1.5 minimum.

Simple geological investigations of the underlying rock by themselves may not be adequate. The rocks lying closely may prove satisfactory as far as their load – bearing characteristics are concerned. If for instance, the dip of the rock strata towards the valley in front is excessive, there is the danger of the anchor block sliding together with underlying rock masses. At greater depths, deposits may be encountered between the rock strata that may become unstable when over – loaded. Hill slides that show evidences of rock slides or avalanches should be avoided.

2.5 Attention for designing Anchor Block for highly headed water

On an account of forces on Anchor Block, Major forces are due to head of water and if Anchor Block is located at the end of Penstock system then **P. S. Nigam [2]** suggested that the lowest anchor block followed by a bend in the penstocks is subject to significantly greater sliding component, originated from water pressure, as compared to the intermediate anchorages. The component tending to displace the anchor is greater; the flatter is the slope of the preceding tangent section. As we proceed downstream, the hydrostatic force due to change of direction becomes more and more significant as regards the stability of the anchorage. In very high head plants; the thrust acting on the lowest anchorage is hardly influenced by the spacing of the latter and will be especially great at the lowest block if it is anchoring an almost horizontal pipe section immediately before the manifold. The end anchorage should be placed at the end of this horizontal section as close to the power station as possible. Thus the unsupported length of the penstock is reduced. A manifold incorporating bends and without intermediate anchorage would be subject to excessive forces resulting in objectionable deformations. The manifold arrangement requires careful analysis.

2.6 Difference of concrete volume for concave and convex bend

P.S. Nigam. [2] suggested that Forces transmitted by the adjacent penstock sections to an anchor block located at a point where the change in slope of the terrain and thus the bend in the penstock, is concave when viewed from above tend to displace the anchor block over the terrain.

These forces have a component normal to the terrain. The magnitude of this depends upon the angle of the bend. This component tends to stabilize the anchor.

At bends, where the penstocks deflect downwards, these are convex when viewed from above. The resultant of forces acting upon the anchor has a component directed away from the terrain and at such places large concrete volumes are usually required to ensure the stability of the block. Intermediate anchor locks are generally spaced at 100 to 150 meters apart. They are necessarily located in long straight reaches. These blocks are subject to a force caused by pipe thrust and approximately parallel to the terrain. Therefore, it constitutes an intermediate case between the first two as far as stability is concerned. The case of the convex bend is the critical case in so far as stability is concerned.

2.7 Minimize the cost of Anchor Block

As per **Penstock [5]** to minimize the cost of Anchor Block

- Keeping the penstock closer to the ground.
- Avoiding tight joints.
- Avoiding soft and unstable ground.

2.8 Safety of Anchor Block

For giving proper safety to Anchor Block, **P.S.Nigam [2]** has given different criteria:

- Anchor should preferably be founded on a rock base. Wherever rock is available at great depths, the stability of overburden material as excavated for anchor block foundation shall be checked against sliding as an earthen slope with anchor block on it and in its natural condition.
- Stable slope cuts shall be provided around the anchor block location so as to safeguard against the possibility of a slide of the slope cut damaging the anchor block foundation.
- Precautions shall be taken to prevent such erosion by neighboring streams as would adversely affect the foundation of the anchor block.
- In high altitude areas where permafrost conditions exist, there are chances of alternate freezing and thawing in the soil. Adequate measures shall be adopted to account for the volume change in the foundation to ensure stability.

3.1 Introduction

Normally, anchor block is subjected to different types of forces, out of which 12 types of forces are of most concern. To analyze anchor block under different forces, all the forces on the anchor block were resolved into horizontal and vertical components. The summation of forces in horizontal and vertical direction was acting at the point of intersection of the centre of the pipe u/s and d/s of the anchor block as shown in Figure 3.1.

3.2 Loads and Forces acting on Anchor Block.

2. Hydrostatic force

According to hydrostatic law **"Whatever may be the inclination of submerged plane surface to the free liquid surface, the magnitude of the resultant hydrostatic force equals to the product of the Area and the pressure at the center of the area."**

So hydrostatic force acting along axis of pipe on each side of bend $(F_s) = w \times A \times H_d$

Where,

w = Unit weight of water

A = Inside area of penstock

H_d = Max head at the centre of pipe including water hammer

3. Dynamic force

In penstock system, there occurs a change in velocity of a steadily moving flow, this change may be magnitude or in direction or in both, which creates Dynamic force.

Magnitude of a force can be calculated by Momentum principle.

According to momentum principle **"The time rate of change of momentum is proportional to the impressed force and takes place in the direction in which force acts."**

Momentum is the product of the mass and velocity.

Fluid mass displaced = $\rho \times A \times ds$

$= \rho \times A \times V \times dt \quad (ds = V \times dt)$

$m = \rho \times Q \times dt$

Now,

Momentum $= m \times V$

$= \rho \times Q \times dt \times V$

$= w / g \times (Q \times V)$

$= w \times Q \times V / g$

So, Dynamic force acting against out - side of bend ***(F_d) = $Q_d \times w \times V / g$***

Where,

Q_d = Design discharge @ 10% overload

w = Unit weight of water

V = Velocity of water in penstock

g = Acceleration due to gravity

4. Force due to dead weight of pipe from anchor uphill to expansion joint

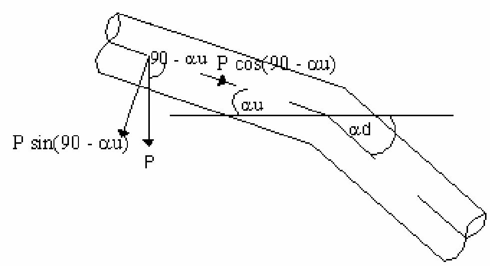


Figure 3.1 Force due to dead weight of pipe from u/s side

As shown in Figure 3.1 self weight of the pipe (P) acting vertically downward making angle of 90 - α_{vu} with the axis of pipe. So P having two components

1. Along the axis of pipe = $P \times \text{Cos}(90 - \alpha_{vu}) = P \times \text{Sin}\alpha_{vu}$

This is taken as the thrust due to self – weight of pipe resisted by the Anchor Block.

Force due to dead weight of pipe from anchor uphill to expansion joint, tending to slide downhill over pier ***(D_u) = $P \times \text{Sin}\,\alpha_{vu}$***

Where,

P = Dead weight of pipe from Anchor uphill to expansion joint

α_{vu} = Vertical angle of penstock with horizontal plane u/s of Anchor.

2. Perpendicular to the axis of pipe = $P \times Sin(90 - \alpha_{vu}) = P \times Cos\alpha_{vu}$

   This force is resisted by the pier provided between two Anchor Block.

4. Force due to dead weight of pipe from anchor downhill to expansion joint,

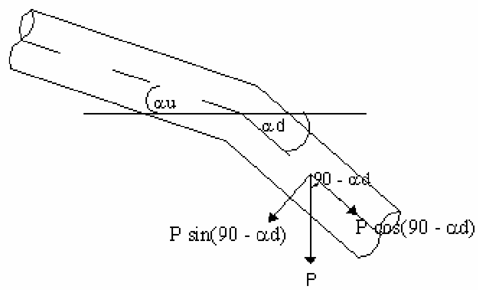


Figure 3.2 Force due to dead of pipe from d/s side

As shown in Figure 3.2 self weight of the pipe (P') acting vertically downward making angle of $90 - \alpha_{vd}$ with the axis of pipe. So P' having two components

1. Along the axis of pipe = $P' \times Cos(90 - \alpha_{vd}) = P' \times Sin\alpha_{vd}$

This is taken as the thrust due to self – weight of pipe resisted by the Anchor Block.

Force due to dead weight of pipe from anchor downhill to expansion joint, tending to slide downhill over pier $(D_d) = P' \times Sin\,\alpha_{vd}$

Where,

P = Dead weight of pipe from Anchor uphill to expansion joint

α_{vd} = Vertical angle of penstock with horizontal plane d/s of Anchor.

2. Perpendicular to the axis of pipe = $P' \times Sin(90 - \alpha_{vd}) = P' \times Cos\alpha_{vd}$

   This force is resisted by the pier provided between two Anchor Block.

5. Sliding friction of pipe on piers due to expansion or contraction uphill from anchor

$(S_{pu}) = f \times Cos\,\alpha_{vu} \times (P + W - p/2)$

Where,

f = Co – efficient of pipe on piers.

P = Dead weight of pipe from anchor uphill to expansion joint.

W = Weight of water in pipe P.

p = Weight of pipe and contained water from anchor to adjacent uphill pier.

α_{vu} = Vertical angle of penstock with horizontal plane d/s of Anchor.

So this much sliding friction of pipe is taken by the number of piers in between two Anchor Blocks on u/s side.

Sliding friction of pipe on one pier due to expansion or contraction uphill from anchor = $(f \times \text{Cos}\alpha_{vu} \times (P + W - p/2)) / n$

n = number of piers in between two Anchor Block.

-p / 2 is for subtracting the weight which will be taken by the Anchor Block, which is not transferred to the pier.

6. **Sliding friction of pipe on piers due to expansion or contraction downhill from anchor**

$(S_{pd}) = f \times Cos\,\alpha_{vd} \times (P' + W' - p'/2)$

Where,

f = Co – efficient of pipe on piers.

P' = Dead weight of pipe from anchor downhill to expansion joint.

W' = Weight of water in pipe P'.

p' = Weight of pipe and contained water from anchor to adjacent downhill pier.

α_{vd} = Vertical angle of penstock with horizontal plane d/s of Anchor.

So this much sliding friction of pipe has to be taken by the number of piers in between two Anchor Blocks on d/s side.

Sliding friction of pipe on one pier due to expansion or contraction downhill from anchor = $(f \times \text{Cos}\alpha_{vu} \times (P' + W' - p'/2)) / n$

n = number of piers in between two Anchor Block.

-p' / 2 is for subtracting the weight which will be taken by the Anchor Block, which is not transferred to the pier.

Sliding friction of pipe on piers due to expansion or contraction downhill from anchor was absent when there was no expansion joint provided between two Anchor Block. The magnitude of these forces depends upon the length and thickness of pipe and water contained in that pipe.

7. **Sliding friction of uphill expansion joint** $(S_{eu}) = f' \times \pi \times (d_u + 2\,t)$

Where,

f ' = Friction of expansion joint per meter of circumference.

d_u = Inside diameter of pipe at uphill expansion joint.

t = Thickness of pipe shell at uphill of anchor.

8. **Sliding friction of downhill expansion joint** $(S_{ed}) = f' \times \pi \times (d_d + 2\,t')$

Where,

f ' = Friction of expansion joint per meter of circumference.

d_d = Inside diameter of pipe at downhill expansion joint.

t' = Thickness of pipe shell at downhill of anchor.

Sliding friction of uphill and downhill expansion joint is absent when there is no expansion joint is provided between Anchor Blocks. Magnitude of force depends upon the diameter of pipe and thickness of pipe shell.

9. Hydrostatic pressure on exposed end of pipe in uphill expansion joint

$(F_u) = w \times a \times H_d$

Where,

w = Unit weight of water

a = C/S area of pipe shell at uphill expansion joint

H_d = Max head at the centre of pipe including water hammer

10. Hydrostatic pressure on exposed end of pipe in downhill expansion joint

$(F_d) = w \times a' \times H_d$

Where,

w = Unit weight of water

a' = C/S area of pipe shell at downhill expansion joint

H_d = Max head at the centre of pipe including water hammer

Hydrostatic pressure on exposed end of pipe in uphill and downhill expansion joint is absence when there is no expansion joint is provided between Anchor Blocks. Magnitude of these forces depends on thickness of pipe shell, which is being exposed at expansion joint.

11. **Longitudinal force due to reducer above anchor** $(L_u) = w \times H_d \times (A' - A)$

Where,

w = Unit weight of water

A' = C/S area of pipe above upper reducer

A = C/S area of pipe at anchor

H_d = Max head at the centre of pipe including water hammer

12. **Longitudinal force due to reducer below anchor** $(L_d) = w \times H_d \times (A - A'')$

Where,

w = Unit weight of water

A" = C/S area of pipe below lower reducer

A = C/S area of pipe at anchor

H_d = Max head at the centre of pipe including water hammer

This force is absence when no Reducer is provided at the anchor block. Reducer is actually provided to increase in velocity of water to get more energy.

3.3 Load combination for different type of condition for Anchor Block

Analysis of Anchor Block was carried out for four different condition listed below, from which for the worst condition designing of Anchor Block is carried out.

1) Pipe is full – expanding condition (temperature rise).

   1. Force on Anchor Block from u/s side

      F_{eus} = LOAD (1 + 2 + 3 + 5 + 7 + 9 + 11)

   2. Force on Anchor Block from d/s side

      F_{eds} = LOAD (- 1 - 2 + 4 - 6 - 8 - 10 + 12)

2) Pipe is full – contracting condition (temperature fall).

1 Force on Anchor Block from u/s side

F_{eus} = LOAD (1 + 2 + 3 - 5 - 7 + 9 + 11)

2 Force on Anchor Block from d/s side

F_{eds} = LOAD (- 1 - 2 + 4 + 6 + 8 - 10 + 12)

3) Pipe is empty – expanding condition.

When the pipe is empty so, hydrostatic, dynamic and force due to reducer is absent.

1 Force on Anchor Block from u/s side

$F_{eus'}$ = LOAD (3 + 5 + 7)

2 Force on Anchor Block from d/s side

$F_{eds'}$ = LOAD (4 - 6 - 8)

4) Pipe is empty – contracting condition.

1 Force on Anchor Block from u/s side

$F_{eus'}$ = LOAD (3 - 5 - 7)

2 Force on Anchor Block from d/s side

$F_{eds'}$ = LOAD (4 + 6 + 8)

3.4 Problem Formulation

For designing Anchor Block data has been taken from the L & T, Chhani, Baroda. Here total five problems of Anchor Block were taken having different pipe bend as illustrated below.

Bend 1: First block of the penstock system having minimum head.

Bend 2: Anchor Block having pipe bend of concave type.

Bend 3: Anchor Block having pipe bend of convex type.

Bend 4: Anchor Block having Horizontal bend of pipe.

Bend 5: Anchor Block having combined bend of pipe.

Bend 1: Analysis of an Anchor Block having steel pipe of internal diameter 1.2 m and thickness 5 mm having discharge of 4.65 cumec with 6 m head of water.

Discharge	Q_{inflow}	4.65	cumec
Net head at the location of anchor block	H_{net}	6.00	m
Additional head due to waterhammer as percentage of net head	P_{surge}	33	%
Percentage of overload	$P_{overload}$	15	%
Co - efficient of pipe on piers (Refer clause 5.5 of IS : 5330 - 1984)	f	0.50	
Co - efficient of friction between packing and liner (Refer clause 5.5.1 of IS : 5330 - 1984)	μ	0.26	
Unit weight of water	w	10	kN/m^3
Packing length	e	0.125	m
Internal dia of pipe of at anchor	D_a	1.20	m
Internal dia of pipe above upper reducer	D_u	1.20	m
Internal dia of pipe below lower reducer	D_l	1.20	m
Thickness of pipe shell (uphill of anchor block)	t	5	mm
Thickness of pipe shell (downhill of anchor block)	t'	5	mm
Density of pipe material	γ	78.50	kN/m^2
Inside dia of pipe	d	1.20	m
Inside dia of pipeshell at uphill of expansion joint	$d_u = d$	1.20	m
Inside dia of pipeshell at downhill of expansion joint	$d_d = d$	1.20	m
Acceleration due to gravity	g	9.81	m/sec^2
Length of pipe from anchor uphill to expansion joint	L_{ue}	2	m
Length of pipe from anchor to adjacent uphill pier	L_{up}	2.00	m
Length of pipe from anchor downhill to expansion joint	L_{de}	5.00	m
Length of pipe from anchor to adjacent downhill pier	L_{dp}	11.1	m
Slope angle of penstock u/s of anchor	α_{vu}	0.00	Degree
Slope angle of penstock d/s of anchor	α_{vd}	19.48	Degree

Bend 2: Analysis of an Anchor Block having steel pipe of internal diameter 1.2 m and thickness 5 mm having discharge of 4.65 cumec with 85.0 m head of water having concave bend of pipe.

Discharge	Q_{inflow}	4.65	cumec
Net head at the location of anchor block	H_{net}	85.00	m
Additional head due to waterhammer as percentage of net head	P_{surge}	33	%
Percentage of overload	$P_{overload}$	15	%
Co - efficient of pipe on piers (Refer clause 5.5 of IS : 5330 - 1984)	f	0.50	
Co - efficient of friction between packing and liner (Refer clause 5.5.1 of IS : 5330 - 1984)	μ	0.26	
Unit weight of water	w	10	kN/m^3
Packing length	e	0.125	m
Internal dia of pipe of at anchor	D_a	1.20	m
Internal dia of pipe above upper reducer	D_u	1.20	m
Internal dia of pipe below lower reducer	D_l	1.20	m
Thickness of pipe shell (uphill of anchor block)	t	5	mm
Thickness of pipe shell (downhill of anchor block)	t'	5	mm
Density of pipe material	γ	78.50	kN/m^2
Inside dia of pipe	d	1.20	m
Inside dia of pipeshell at uphill of expansion joint	$d_u = d$	1.20	m
Inside dia of pipeshell at downhill of expansion joint	$d_d = d$	1.20	m
Acceleration due to gravity	g	9.81	m/sec^2
Length of pipe from anchor uphill to expansion joint	L_{ue}	119.33	m
Length of pipe from anchor to adjacent uphill pier	L_{up}	7.50	m
Length of pipe from anchor downhill to expansion joint	L_{de}	5.00	m
Length of pipe from anchor to adjacent downhill pier	L_{dp}	7.50	m
Slope angle of penstock u/s of anchor	α_{vu}	36.43	Degree
Slope angle of penstock d/s of anchor	α_{vd}	13.54	Degree

Bend 3: Analysis an Anchor Block having steel pipe of internal diameter 1.2 m and thickness 5 mm having discharge of 4.65 cumec with 85.0 m head of water having convex bend of pipe.

Discharge	Q_{inflow}	4.65	cumec
Net head at the location of anchor block	H_{net}	85.00	m
Additional head due to waterhammer as percentage of net head	P_{surge}	33	%
Percentage of overload	$P_{overload}$	15	%
Co - efficient of pipe on piers (Refer clause 5.5 of IS : 5330 - 1984)	f	0.50	
Co - efficient of friction between packing and liner (Refer clause 5.5.1 of IS : 5330 - 1984)	μ	0.26	
Unit weight of water	w	10	kN/m^3
Packing length	e	0.125	m
Internal dia of pipe of at anchor	D_a	1.20	m
Internal dia of pipe above upper reducer	D_u	1.20	m
Internal dia of pipe below lower reducer	D_l	1.20	m
Thickness of pipe shell (uphill of anchor block)	t	5	mm
Thickness of pipe shell (downhill of anchor block)	t'	5	mm
Density of pipe material	γ	78.50	kN/m^2
Inside dia of pipe	d	1.20	m
Inside dia of pipeshell at uphill of expansion joint	$d_u = d$	1.20	m
Inside dia of pipeshell at downhill of expansion joint	$d_d = d$	1.20	m
Acceleration due to gravity	g	9.81	m/sec^2
Length of pipe from anchor uphill to expansion joint	L_{ue}	119.33	m
Length of pipe from anchor to adjacent uphill pier	L_{up}	7.50	m
Length of pipe from anchor downhill to expansion joint	L_{de}	5.00	m
Length of pipe from anchor to adjacent downhill pier	L_{dp}	7.50	m
Slope angle of penstock u/s of anchor	α_{vu}	16.70	Degree
Slope angle of penstock d/s of anchor	α_{vd}	34.22	Degree

Bend 4: Analysis of an Anchor Block having steel pipe of internal diameter 1.1 m and thickness 10 mm having discharge of 4.77 cumec with 75.80 m head of water having horizontal bend of pipe without expansion joint.

Discharge	Q_{inflow}	4.77	cumec
Net head at the location of anchor block	H_{net}	75.80	m
Additional head due to waterhammer as percentage of net head	P_{surge}	33	%
Percentage of overload	$P_{overload}$	15	%
Co - efficient of pipe on piers (Refer clause 5.5 of IS : 5330 - 1984)	f	0.50	
Co - efficient of friction between packing and liner	μ	0.26	
(Refer clause 5.5.1 of IS : 5330 - 1984)			
Unit weight of water	w	10	kN/m^3
Packing length	e	0.125	m
Internal dia of pipe of at anchor	D_a	1.10	m
Internal dia of pipe above upper reducer	D_u	1.10	m
Internal dia of pipe below lower reducer	D_l	1.10	m
Thickness of pipe shell (uphill of anchor block)	t	10	mm
Thickness of pipe shell (downhill of anchor block)	t'	10	mm
Density of pipe material	γ	78.50	kN/m^2
Inside dia of pipe	d	1.10	m
Inside dia of pipeshell at uphill of expansion joint	$d_u = d$	1.10	m
Inside dia of pipeshell at downhill of expansion joint	$d_d = d$	1.10	m
Acceleration due to gravity	g	9.81	m/sec^2
Length of pipe from anchor uphill to expansion joint	L_{ue}	4.95	m
Length of pipe from anchor to adjacent uphill pier	L_{up}	0	m
Length of pipe from anchor downhill to expansion joint	L_{de}	7.68	m
Length of pipe from anchor to adjacent downhill pier	L_{dp}	0	m
Vertical angle of Penstock with the horizontal plane u/s of anchor	α_{vu}	0	Degree
Vertical angle of Penstock with the horizontal plane d/s of anchor	α_{vd}	0	Degree
Horizontal angle subtended by the penstock with the centre axis in u/s	α_{hu}	45	Degree
Horizontal angle subtended by the penstock with the centre axis in d/s	α_{hd}	0	Degree

Bend 5: Analysis of an Anchor Block having steel pipe of internal diameter 1.2 m and thickness 5 mm having discharge of 4.77 cumec with 135.0 m head of water having combined bend of pipe.

Discharge	Q_{inflow}	4.77	cumec
Net head at the location of anchor block	H_{net}	135.00	m
Additional head due to waterhammer as percentage of net head	P_{surge}	33	%
Percentage of overload	$P_{overload}$	15	%
Co - efficient of pipe on piers(Refer clause 5.5 of IS : 5330 - 1984)	f	0.50	
Co - efficient of friction between packing and liner	μ	0.26	
(Refer clause 5.5.1 of IS : 5330 - 1984)			
Unit weight of water	w	10	kN/m^3
Packing length	e	0.125	m
Internal dia of pipe of at anchor	D_a	1.20	m
Internal dia of pipe above upper reducer	D_u	1.20	m
Internal dia of pipe below lower reducer	D_l	1.20	m
Thickness of pipe shell (uphill of anchor block)	t	5	mm
Thickness of pipe shell (downhill of anchor block)	t'	5	mm
Density of pipe material	γ	78.50	kN/m^2
Inside dia of pipe	d	1.20	m
Inside dia of pipeshell at uphill of expansion joint	$d_u = d$	1.20	m
Inside dia of pipeshell at downhill of expansion joint	$d_d = d$	1.20	m
Acceleration due to gravity	g	9.81	m/sec^2
Length of pipe from anchor uphill to expansion joint	L_{ue}	53.91	m
Length of pipe from anchor to adjacent uphill pier	L_{up}	7.50	m
Length of pipe from anchor downhill to expansion joint	L_{de}	28.93	m
Length of pipe from anchor to adjacent downhill pier	L_{dp}	0	m
Vertical angle of Penstock with the horizontal plane u/s of anchor	α_{vu}	23.81	Degree
Vertical angle of Penstock with the horizontal plane d/s of anchor	α_{vd}	32.11	Degree
Horizontal angle subtended by the penstock with the centre axis in u/s	α_{hu}	0	Degree
Horizontal angle subtended by the penstock with the centre axis in ds	α_{hd}	24.36	Degree

3.5 Analysis of Anchor Block

Analysis was done to find out net forces from pipe on Anchor Block. Bend 1 was provided at the starting location of penstock system, having minimum head of water. U/s pipe reaching straight in to the Anchor Block therefore there was no force due to deadweight of pipe from u/s side of Anchor Block.

3.5.1 Bend 1

Max head at any point including water hammer (H_d) = $H_{net} \times (1 + P_{surge} / 100)$

$= 6 \times (1 + 33 / 100)$

$= 7.98$ m

Friction of expansion joint per meter of circumference

$(f') = 1.5 \times \mu \times w \times e \times H$

$= 1.5 \times 0.26 \times 1000 \times 0.125 \times 7.98$

$= 3890.25$

C/S area of pipe at anchor (A) = $\pi/4 \times D_a^2$

$= \pi/4 \times (1.2)^2$

$= 1.13$ m^2

C/S area of pipe above upper reducer (A') = $\pi/4 \times D_u^2$

$= \pi/4 \times (1.2)^2$

$= 1.13$ m^2

C/S area of pipe below lower reducer (A'') = $\pi/4 \times D_l^2$

$= \pi/4 \times (1.2)^2$

$= 1.13$ m^2

C/S area of pipeshell at uphill of expansion joint (a) = $\pi \times (t / 1000) \times (d_u + (t / 1000))$

$= \pi \times 0.005 \times (1.2 + 0.005)$

$= 0.019$ m^2

C/S area of pipeshell at downhill of expansion joint (a') = $\pi \times (t'/ 1000) \times (d_l + (t' / 1000))$

$= \pi \times 0.005 \times (1.2 + 0.005)$

$= 0.019$ m^2

Design discharge $Q_d = (1 + P_{overload} / 100) \times Q_{inflow}$

$= (1 + 15 / 100) \times 4.65$

$= 5.35\ m^3$

Velocity $(V) = Q_d / A$

$= 5.35 / 1.13$

$= 4.73\ m / sec$

Dead weight of pipe from anchor uphill to expansion joint $(P) = L_{ue} \times a \times \gamma$

$= 2 \times 0.019 \times 7.85 \times 10000$

$= 2971.72\ N$

Weight of water in pipe P $(W) = L_{ue} \times A' \times w$

$= 2 \times 1.13 \times 10 \times 1000$

$= 22619.52\ N$

Dead weight of pipe from anchor downhill to expansion joint $(P') = L_{de} \times a' \times \gamma$

$= 5 \times 0.019 \times 7.85 \times 10000$

$= 7429.29\ N$

Weight of water in pipe P' $(W') = L_{de} \times A'' \times w$

$= 5 \times 1.13 \times 10 \times 1000$

$= 56548.8\ N$

Weight of pipe and contained water from anchor to adjacent uphill pier

$(p) = L_{up} / L_{ue} \times (P + W)$

$= 2 / 2 \times (2971.72 + 22619.52)$

$= 25591.23\ N$

Weight of pipe and contained water from anchor to adjacent downhill pier

$(P') = L_{dp} / L_{de} \times (P' + W')$

As such $L_{dp} > L_{de}$

So, $(P') = P' + W'$

$= (7429.29 + 56548.80)$

$= 63978.7\ N$

- **Loads and forces acting on anchor block:**

1. Hydrostatic force acting along axis of pipe on each side of bend

   $F_s = w \times A \times H_d$

   $= 10 \times 1000 \times 1.13 \times 7.98$

   $= 90251.89$ N

2. Dynamic force acting against out - side of bend

   $F_d = Q_d \times w \times V / g$

   $= 5.35 \times 10 \times 1000 \times 4.73 / 9.81$

   $= 25773.84$ N

3. Force due to dead weight of pipe from anchor uphill to expansion joint, tending to slide downhill over pier

   $D_u = P \times \text{Sin}\ (\alpha_{vu})$

   $= 2971.72 \times \text{Sin}\ 0 = 0$

4. Force due to dead weight of pipe from anchor downhill to expansion joint, tending to slide downhill over pier

   $D_d = P' \times \text{Sin}\ (\alpha_{vd})$

   $= 7429.29 \times \text{Sin}\ (19.48)$

   $= 2477.57$ N

5. Sliding friction of pipe on piers due to expansion or contraction uphill from anchor

   $S_{pu} = f \times \text{Cos}\ (\alpha_{vu}) \times (P + W - p / 2)$

   $= 0.5 \times \text{Cos}\ (0) \times (2971.72\ 9 + 22619.52 - 25591.23 / 2)$

   $= 6397.81$

6. Sliding friction of pipe on piers due to expansion or contraction downhill from anchor

   $S_{pd} = f \times \text{Cos}\ (\alpha_{vu}) \times (P' + W' - p' / 2)$

   $= 0.5 \times \text{Cos}\ (19.48) \times (2971.72\ 9 + 22619.52 - 25591.23 / 2)$

   $= 6397.81 \times 0.94 \times (7429.29 + 56548.8 - 63978.7 / 2)$

   $= 15078.91$ N

7. Sliding friction of uphill expansion joint

   $S_{eu} = f' \times \pi \times (d + 2 \times t)$

   $= 3890.25 \times \pi \times (1.2 + 2 \times (0.005))$

   $= 14788.15$ N

8. Sliding friction of downhill expansion joint

$S_{ed} = f' \times \pi \times (d + 2 \times t')$

$= 3890.25 \times \pi \times (1.2 + 2 \times (0.005))$

$= 14788.15$ N

9. Hydrostatic pressure on exposed end of pipe in uphill expansion joint

$F_u = w \times a \times H_d$

$= 10 \times 1000 \times 0.019 \times 7.98$

$= 1510.47$ N

10. Hydrostatic pressure on exposed end of pipe in downhill expansion joint

$F_d = w \times a' \times H_d$

$= 10 \times 1000 \times 0.019 \times 7.98$

$= 1510.47$ N

11. Longitudinal force due to reducer above anchor

$L_u = w \times H_d \times (A' - A)$

$= 10 \times 1000 \times 7.98 \times (0)$

$= 0$

12. Longitudinal force due to reducer below anchor

$L_d = w \times H_d \times (A' - A)$

$= 10 \times 1000 \times 7.98 \times (0)$

$= 0$

- **Governing Case:**

We had gone for expansion and contraction for penstock full and empty condition. Dynamic force was the major force when penstock full condition was there. Among 12 forces 7 forces comes from u/s side and 7 forces comes from d/s side of the Anchor Block. Hydrostatic force and Dynamic force acts at u/s side as well as at d/s side. Sliding friction of pipe on piers uphill from anchor or downhill from anchor acts in opposite direction for expansion and contraction condition, same for sliding friction for expansion and contraction acts in opposite direction as shown in Figure 3.3 Now we see the governing condition among four conditions.

Case 1: Expansion and Penstock Full Condition

Force on Anchor Block from u/s side

F_{eus} = Load (1 + 2 + 3 + 5 + 7 + 9 +11)

= 90251.89 + 25773.84 + 0 + 6397.81 + 14788.15 + 1510.47 + 0

= 138722.15 N

Force on Anchor Block from d/s side

F_{eds} = Load (- 1 - 2 + 4 - 6 - 8 - 10 +12)

= -90251.89 - 25773.84 + 2477.57 - 15078.91 - 14788.15 - 1510.47 + 0

= -144925.68 N

Case 2: Contraction and Penstock Full Condition

Force on Anchor Block from u/s side

F_{cus} = Load (1 + 2 + 3 - 5 - 7 + 9 +11)

= 90251.89 + 25773.84 + 0 - 6397.81 - 14788.15 + 1510.47 + 0

= 96350.23 N

Force on Anchor Block from d/s side

F_{cds} = Load (- 1 - 2 + 4 + 6 + 8 - 10 +12)

= -90251.89 - 25773.84 + 2477.57 + 15078.91 + 14788.15 - 1510.47 + 0

= -85191.56 N

Case 3: Expansion and Penstock Empty Condition

Force on Anchor Block from u/s side

$F_{eus'}$ = Load (3 + 5)

= 0 + 742.93

= 742.93 N

Force on Anchor Block from d/s side

$F_{eds'}$ = Load (4 - 6)

= 2477.57 - 1751

= 726.57 N

Case 4: Contraction and Penstock Empty Condition

Force on Anchor Block from u/s side

$F_{cus'}$ = Load (3 - 5)

= 0 – 742.93

= -742.93 N

Force on Anchor Block from d/s side

$F_{cds'}$ = Load (4 + 6)

= 2477.57 + 1751

= 4228.57 N

Here, $F_{eus} > F_{cus}$ and Feds < F_{cds}

So, **Case 1** was the governing case

3.5.2 Bend 2

Bend 2 which was provided with concave type of pipe bend with 85.0 m head of water. Here expansion joint is provided just after Anchor Block for d/s side before pier, so we have to take the full length of pipe load from Anchor Block to expansion joint rather than taking half length of pipe load which was taken by pier. Here Anchor Block was provided without Reducer therefore no longitudinal forces are created in Anchor Block.

Max head at any point including water hammer (H_d) = $H_{net} \times (1 + P_{surge} / 100)$

$= 85 \times (1 + 33 / 100)$

= 113.05 m

Friction of expansion joint per meter of circumference

$(f\,') = 1.5 \times \mu \times w \times e \times H$

$=1.5 \times 0.26 \times 1000 \times 0.125 \times 113.05$

= 3890.25

C/S area of pipe at anchor (A) = $\pi/4 \times D_a^2$

$= \pi/4 \times (1.2)^2$

= 1.13 m^2

C/S area of pipe above upper reducer (A') = $\pi/4 \times D_u^2$

$= \pi/4 \times (1.2)^2$

$= 1.13\ m^2$

C/S area of pipe below lower reducer (A") = $\pi/4 \times D_l^{2.}$

$= \pi/4 \times (1.2)^2$

$= 1.13\ m^2$

C/S area of pipeshell at uphill of expansion joint (a) = $\pi \times (t / 1000) \times (d_u + (t / 1000))$

$= \pi \times 0.005 \times (1.2 + 0.005)$

$= 0.019\ m^2$

C/S area of pipeshell at downhill of expansion joint (a') = $\pi \times (t'/ 1000) \times (d_l + (t' / 1000))$

$= \pi \times 0.005 \times (1.2 + 0.005)$

$= 0.019\ m^2$

Design discharge $Q_d = (1+ P_{overload} / 100) \times Q_{inflow}$

$= (1 + 15 / 100) \times 4.65$

$= 5.35\ m^3$

Velocity (V) = Q_d / A

$= 5.35 / 1.13$

$= 4.73$ m / sec

Dead weight of pipe from anchor uphill to expansion joint

(P) = $L_{ue} \times a \times \gamma$

$= 119.03 \times 0.019 \times 7.85 \times 10000$

$= 177307.6$ N

Weight of water in pipe P (W) = $L_{ue} \times A' \times w$

$= 119.03 \times 1.13 \times 10 \times 1000$

$= 1349594$ N

Dead weight of pipe from anchor downhill to expansion joint

(P') = $L_{de} \times a' \times \gamma$

$= 5 \times 0.019 \times 7.85 \times 10000$

$= 7429.29$ N

Weight of water in pipe P' (W') = $L_{de} \times A'' \times w$

$= 5 \times 1.13 \times 10 \times 1000$

$= 56548.8$ N

Weight of pipe and contained water from anchor to adjacent uphill pier

$(p) = L_{up} / L_{ue} \times (P + W)$

$= 7.5 / 119.03 \times (2971.72 + 22619.52)$

$= 95967.14$ N

Weight of pipe and contained water from anchor to adjacent downhill pier

$(p') = L_{dp} / L_{de} \times (P' + W')$

As such $L_{dp} > L_{de}$

So, $(p') = P' + W'$

$= (7429.29 + 56548.80)$

$= 63978.7$ N

- **Loads and forces acting on anchor block:**

1. Hydrostatic force acting along axis of pipe on each side of bend

   $F_s = w \times A \times H_d$

   $= 10 \times 1000 \times 1.13 \times 113.05$

   $= 1278568.4$ N

2. Dynamic force acting against out - side of bend

   $F_d = Q_d \times w \times V / g$

   $= 5.35 \times 10 \times 1000 \times 4.73 / 9.81$

   $= 25773.84$ N

3. Force due to dead weight of pipe from anchor uphill to expansion joint, tending to slide downhill over pier

   $D_u = P \times \text{Sin}(\alpha_{vu})$

   $= 177307.6 \times \text{Sin } 36.43$

   $= 105887.6$ N

4. Force due to dead weight of pipe from anchor downhill to expansion joint, tending to slide downhill over pier

   $D_d = P' \times \text{Sin}(\alpha_{vd})$

   $= 7429.29 \times \text{Sin}(13.54)$

   $= 1765.96$ N

5. Sliding friction of pipe on piers due to expansion or contraction uphill from anchor

$S_{pu} = f \times \mathrm{Cos}\ (\alpha_{vu}) \times (P + W - p / 2)$

$= 0.5 \times \mathrm{Cos}\ (36.43) \times (177307.6 + 1349594 - 95967.14 / 2)$

$= 593116.78$

6. Sliding friction of pipe on piers due to expansion or contraction downhill from anchor

$S_{pd} = f \times \mathrm{Cos}\ (\alpha_{vd}) \times (P' + W' - p' / 2)$

$= 0.5 \times \mathrm{Cos}\ (13.54) \times (7429.9 + 56548.8 - 63978.7 / 2)$

$= 6397.81 \times 0.94 \times (7429.29 + 56548.8 - 63978.7 / 2)$

$= 15536.09$ N

7. Sliding friction of uphill expansion joint

$S_{eu} = f' \times \pi \times (d + 2 \times t)$

$= 55111.88 \times \pi \times (1.2 + 2 \times (0.005))$

$= 209498.75$ N

8. Sliding friction of downhill expansion joint

$S_{ed} = f' \times \pi \times (d + 2 \times t')$

$= 55111.88 \times \pi \times (1.2 + 2 \times (0.005))$

$= 209498.75$ N

9. Hydrostatic pressure on exposed end of pipe in uphill expansion joint

$F_u = w \times a \times H_d$

$= 10 \times 1000 \times 0.019 \times 113.05$

$= 21398.26$ N

10. Hydrostatic pressure on exposed end of pipe in downhill expansion joint

$F_d = w \times a' \times H_d$

$= 10 \times 1000 \times 0.019 \times 113.05$

$= 21398.26$ N

11. Longitudinal force due to reducer above anchor

$L_u = w \times H_d \times (A' - A)$

$= 10 \times 1000 \times 113.05 \times (0)$

$= 0$

12. Longitudinal force due to reducer below anchor

$L_d = w \times H_d \times (A' - A)$

$= 10 \times 1000 \times 113.05 \times (0) = 0$

- **Governing Case:**

Due to high head of water hydrostatic force was the major force and also due to long length of pipe on u/s side, force due to dead weight of pipe from anchor uphill to expansion joint was also the major force. Here now we were saw the governing case among four different conditions.

Case 1: Expansion and Penstock Full Condition

Force on Anchor Block from u/s side

F_{eus} = Load (1 + 2 + 3 + 5 + 7 + 9 +11)

= 1278568.4 + 25773.84 + 105887.26 + 593116.78 + 209498.75 + 21398.26 + 0

= 2234243.27 N

Force on Anchor Block from d/s side

F_{eds} = Load (- 1 - 2 + 4 - 6 - 8 - 10 +12)

= -1278568.4 - 25773.84 + 1765.96 - 15536.09 - 209498.75 - 21398.26 + 0

= -1549009.35 N

Case 2: Contraction and Penstock Full Condition

Force on Anchor Block from u/s side

F_{cus} = Load (1 + 2 + 3 - 5 - 7 + 9 +11)

= 1278568.4 + 25773.84 + 105887.26 - 593116.78 - 209498.75 + 21398.26 + 0

= 629012.20N

Force on Anchor Block from d/s side

F_{cds} = Load (- 1 - 2 + 4 + 6 + 8 - 10 +12)

= -1278568.4 - 25773.84 + 1765.96 - 15536.09 - 209498.75 - 21398.26 + 0

= -1098939.7 N

Case 3: Expansion and Penstock Empty Condition

Force on Anchor Block from u/s side

$F_{eus'}$ = Load (3 + 5)

= 105887.26 + 68874.19 = 174761.45 N

Force on Anchor Block from d/s side

$F_{eds'}$ = Load (4 - 6)

= 1765.96 – 1804.09

= -38.13 N

Case 4: Contraction and Penstock Empty Condition

Force on Anchor Block from u/s side

$F_{cus'}$ = Load (3 - 5)

= 105887.26 – 68874.49

= -37012.77 N

Force on Anchor Block from d/s side

$F_{cds'}$ = Load (4 + 6)

= 1765.96 + 1804.09

= 3570.05 N

Here, $F_{eus} > F_{cus}$ and Feds < F_{cds}

So, **Case 1** will be the governing case

3.5.3 Bend 3

To made comparison between concave type and convex type bend, data was same except the pipe bend.

Max head at any point including water hammer (H_d) = $H_{net} \times (1 + P_{surge} / 100)$

$= 85 \times (1 + 33 / 100)$

= 113.05 m

Friction of expansion joint per meter of circumference

$(f ') = 1.5 \times \mu \times w \times e \times H$

$=1.5 \times 0.26 \times 1000 \times 0.125 \times 113.05$

= 3890.25

C/S area of pipe at anchor (A) = $\pi/4 \times D_a^2$

$= \pi/4 \times (1.2)^2$

. $= 1.13\ m^2$

C/S area of pipe above upper reducer (A') $= \pi/4 \times D_u^2$

$= \pi/4 \times (1.2)^2$

$= 1.13\ m^2$

C/S area of pipe below lower reducer (A") $= \pi/4 \times D_l^{2.}$

$= \pi/4 \times (1.2)^2$

$= 1.13\ m^2$

C/S area of pipeshell at uphill of expansion joint (a) $= \pi .\times (t / 1000) \times (d_u + (t / 1000))$

$= \pi \times 0.005 \times (1.2 + 0.005)$

$= 0.019\ m^2$

C/S area of pipeshell at downhill of expansion joint (a') $= \pi \times (t'/ 1000) \times (d_l + (t' / 1000))$

$= \pi \times 0.005 \times (1.2 + 0.005)$

$= 0.019\ m^2$

Design discharge $Q_d = (1+ P_{overload} / 100) \times Q_{inflow}$

$= (1 + 15 / 100) \times 4.65$

$= 5.35\ m^3$

Velocity (V) $= Q_d / A$

$= 5.35 / 1.13$

$= 4.73$ m / sec

Dead weight of pipe from anchor uphill to expansion joint

(P) $= L_{ue} \times a \times \gamma$

$= 119.03 \times 0.019 \times 7.85 \times 10000$

$= 177307.6$ N

Weight of water in pipe P (W) $= L_{ue} \times A' \times w$

$= 119.03 \times 1.13 \times 10 \times 1000$

$= 1349594$ N

Dead weight of pipe from anchor downhill to expansion joint

(P') $= L_{de} \times a' \times \gamma$

$= 5 \times 0.019 \times 7.85 \times 10000$

$= 7429.29$ N

Weight of water in pipe P' (W') $= L_{de} \times A'' \times w$

$= 5 \times 1.13 \times 10 \times 1000$

$= 56548.8$ N

Weight of pipe and contained water from anchor to adjacent uphill pier

(p) $= L_{up} / L_{ue} \times (P + W)$

$= 7.5 / 119.03 \times (2971.72 + 22619.52)$

$= 95967.14$ N

Weight of pipe and contained water from anchor to adjacent downhill pier

(P') $= L_{dp} / L_{de} \times (P' + W')$

As such $L_{dp} > L_{de}$

So, (P') = P' + W'

$= (7429.29 + 56548.80)$

$= 63978.7$ N

- **Loads and Forces Acting On Anchor Block**

1. Hydrostatic force acting along axis of pipe on each side of bend

   $F_s = w \times A \times H_d$

   $= 10 \times 1000 \times 1.13 \times 113.05$

   $= 1278568.4$ N

2. Dynamic force acting against out - side of bend

   $F_d = Q_d \times w \times V / g$

   $= 5.35 \times 10 \times 1000 \times 4.73 / 9.81$

   $= 25773.84$ N

3. Force due to dead weight of pipe from anchor uphill to expansion joint, tending to slide downhill over pier

   $D_u = P \times \text{Sin}\ (\alpha_{vu})$

   $= 177307.6 \times \text{Sin}\ 16.7$

   $= 50701.49$ N

4. Force due to dead weight of pipe from anchor downhill to expansion joint, tending to slide downhill over pier

   $D_d = P' \times \text{Sin}\ (\alpha_{vd})$

   $= 7429.29 \times \text{Sin}\ (34.22)$

$= 4194.90$ N

5. Sliding friction of pipe on piers due to expansion or contraction uphill from anchor

   $S_{pu} = f \times \text{Cos}(\alpha_{vu}) \times (P + W - p / 2)$

   $= 0.5 \times \text{Cos}(16.7) \times (177307.6 + 1349594 - 95967.14 / 2)$

   $= 708581.89$ N

6. Sliding friction of pipe on piers due to expansion or contraction downhill from anchor

   $S_{pd} = f \times \text{Cos}(\alpha_{vd}) \times (P' + W' - p' / 2)$

   $= 0.5 \times \text{Cos}(34.22) \times (7429.9 + 56548.8 - 63978.7 / 2)$

   $= 6397.81 \times 0.83 \times (7429.29 + 56548.8 - 63978.7 / 2)$

   $= 13200.85$ N

7. Sliding friction of uphill expansion joint

   $S_{eu} = f' \times \pi \times (d + 2 \times t)$

   $= 55111.88 \times \pi \times (1.2 + 2 \times (0.005))$

   $= 209498.75$ N

8. Sliding friction of downhill expansion joint

   $S_{ed} = f' \times \pi \times (d + 2 \times t')$

   $= 55111.88 \times \pi \times (1.2 + 2 \times (0.005))$

   $= 209498.75$ N

9. Hydrostatic pressure on exposed end of pipe in uphill expansion joint

   $F_u = w \times a \times H_d$

   $= 10 \times 1000 \times 0.019 \times 113.05$

   $= 21398.26$ N

10. Hydrostatic pressure on exposed end of pipe in downhill expansion joint

    $F_d = w \times a' \times H_d$

    $= 10 \times 1000 \times 0.019 \times 113.05$

    $= 21398.26$ N

11. Longitudinal force due to reducer above anchor

    $L_u = w \times H_d \times (A' - A)$

    $= 10 \times 1000 \times 113.05 \times (0)$

    $= 0$

12. Longitudinal force due to reducer below anchor

$L_d = w \times H_d \times (A' - A)$

$= 10 \times 1000 \times 113.05 \times (0) = 0$

- **Governing Case:**

Here we were go for calculating net forces from pipe on Anchor Block for different condition as listed below.

Case 1: Expansion and Penstock Full Condition

Force on Anchor Block from u/s side

F_{eus} = Load (1 + 2 + 3 + 5 + 7 + 9 +11)

= 1278568.4 + 25773.84 + 50701.49 + 708581.89 + 209498.75 + 21398.26 + 0

= 2294522.60 N

Force on Anchor Block from d/s side

F_{eds} = Load (- 1 - 2 + 4 - 6 - 8 - 10 +12)

= -1278568.4 - 25773.84 + 4194.90 - 13200.85 - 209498.75 - 21398.26 + 0

= -1544245.18 N

Case 2: Contraction and Penstock Full Condition

Force on Anchor Block from u/s side

F_{cus} = Load (1 + 2 + 3 - 5 - 7 + 9 +11)

= 1278568.4 + 25773.84 + 50701.49 - 708581.89 - 209498.75 + 21398.26 + 0

= 458361.32 N

Force on Anchor Block from d/s side

F_{cds} = Load (- 1 - 2 + 4 + 6 + 8 - 10 +12)

= -1278568.4 - 25773.84 + 4194.90 + 13200.85 + 209498.75 - 21398.26 + 0

= -1098846 N

Case 3: Expansion and Penstock Empty Condition

Force on Anchor Block from u/s side

$F_{eus'}$ = Load (3 + 5)

= 50701.49 + 82282.28

= 132983.77 N

Force on Anchor Block from d/s side

$F_{eds'}$ = Load (4 - 6)

= 4194.60 – 1532.92

= 2661.98 N

Case 4: Contraction and Penstock Empty Condition

Force on Anchor Block from u/s side

$F_{cus'}$ = Load (3 - 5)

= 50701.49 - 82282.28

= -31580.80 N

Force on Anchor Block from d/s side

$F_{cds'}$ = Load (4 + 6)

= 4194.60 + 1532.92

= 5727.81 N

Here, $F_{eus} > F_{cus}$ and Feds < F_{cds}

So, **Case 1** will be the governing case

3.5.4 Bend 4

Bend 4 was provided with simple horizontal bend having 75.80 m head of water. This bend was provided without expansion joint, therefore for calculating dead weight of pipe and water in that pipe, we had considered whole length of pipe rather that length up to pier.

Max head at any point including water hammer (H_d) = $H_{net} \times (1 + P_{surge} / 100)$

= $75.80 \times (1 + 33 / 100)$

$= 100.82$ m

Friction of expansion joint per meter of circumference

$(f') = 1.5 \times \mu \times w \times e \times H$

$= 1.5 \times 0.26 \times 1000 \times 0.125 \times 100.82$

$= 48215.58$

C/S area of pipe at anchor (A) $= \pi/4 \times D_a^2$

$= \pi/4 \times (1.1)^2$

$= 0.95\ m^2$

C/S area of pipe above upper reducer (A') $= \pi/4 \times D_u^2$

$= \pi/4 \times (1.1)^2$

$= 0.95\ m^2$

C/S area of pipe below lower reducer (A'') $= \pi/4 \times D_l^2$.

$= \pi/4 \times (1.1)^2$

$= 0.95\ m^2$

C/S area of pipeshell at uphill of expansion joint (a) $= \pi \times (t / 1000) \times (d_u + (t / 1000))$

$= \pi \times 0.005 \times (1.1 + 0.01)$

$= 0.035\ m^2$

C/S area of pipeshell at downhill of expansion joint (a') $= \pi \times (t'/ 1000) \times (d_l + (t' / 1000))$

$= \pi \times 0.005 \times (1.1 + 0.01)$

$= 0.035\ m^2$

Design discharge $Q_d = (1 + P_{overload} / 100) \times Q_{inflow}$

$= (1 + 15 / 100) \times 4.77$

$= 5.49\ m^3$

Velocity (V) $= Q_d / A$

$= 5.49 / 0.95$

$= 5.78$ m / sec

Dead weight of pipe from anchor uphill to expansion joint

$(P) = L_{ue} \times a \times \gamma$

$= 4.95 \times 0.035 \times 7.85 \times 10000$

$= 13292.84$ N

Weight of water in pipe P (W) $= L_{ue} \times A' \times w$

$= 4.95 \times 0.95 \times 10 \times 1000$

$= 46147.74$ N

Dead weight of pipe from anchor downhill to expansion joint

$(P') = L_{de} \times a' \times \gamma$

$= 7.68 \times 0.035 \times 7.85 \times 10000$

$= 20615.98$ N

Weight of water in pipe P' $(W') = L_{de} \times A'' \times w$

$= 7.68 \times 0.95 \times 10 \times 1000$

$= 71570.96$ N

Weight of pipe and contained water from anchor to adjacent uphill pier

$(p) = L_{up} / L_{ue} \times (P + W)$

As such $L_{up} = 0$

So $(p) = P + W$

$= (13292.84 + 46147.74)$

$= 59440.58$ N

Weight of pipe and contained water from anchor to adjacent downhill pier

$(p') = L_{dp} / L_{de} \times (P' + W')$

As such $L_{dp} > L_{de}$

So, $(p') = P' + W'$

$= (20615.98 + 71570.96)$

$= 92186.94$ N

- **Loads and forces acting on anchor block:**

1. Hydrostatic force acting along axis of pipe on each side of bend

   $F_s = w \times A \times H_d$

   $= 10 \times 1000 \times 1.13 \times 100.82$

   $= 939915.99$ N

2. Dynamic force acting against out - side of bend

   $F_d = Q_d \times w \times V / g$

   $= 5.49 \times 10 \times 1000 \times 5.77 / 9.81$

   $= 31663.3$ N

3. Force due to dead weight of pipe from anchor uphill to expansion joint, tending to slide downhill over pier

   $D_u = P \times \text{Sin}\ (\alpha_{vu})$

   $= 177307.6 \times \text{Sin}\ 0$

   $= 0$

4. Force due to dead weight of pipe from anchor downhill to expansion joint, tending to slide downhill over pier

   $D_d = P' \times \text{Sin}\ (\alpha_{vd})$

   $= 7429.29 \times \text{Sin}\ (0)$

   $= 0$

5. Longitudinal force due to reducer above anchor

   $L_u = w \times H_d \times (A' - A)$

   $= 10 \times 1000 \times 113.05 \times (0)$

   $= 0$

6. Longitudinal force due to reducer below anchor

   $L_d = w \times H_d \times (A' - A)$

   $= 10 \times 1000 \times 113.05 \times (0)$

   $= 0$

- **Governing Case:**

Bend 4 was provided with only horizontal bend, therefore Force due to dead weight of pipe from anchor uphill or down hill to expansion joint was absent. Bend was also provided without expansion joint, therefore forces due to sliding friction and due to exposed end of pipe was absent. So, when penstock was empty there was no force transferred to Anchor Block. Here we can see that case 1 as well as case was governing.

Case 1: Expansion and Penstock Full Condition

Force on Anchor Block from u/s side

F_{eus} = Load (1 + 2 + 3 + 5 + 7 + 9 +11)

= 939915.99 + 15853.09 + 0 + 0 = 955769.09 N

Force on Anchor Block from d/s side

F_{eds} = Load (- 1 - 2 + 4 - 6 - 8 - 10 +12)

= -939915.99 - 15853.09 + 0 + 0

= -955769.09 N

Case 2: Contraction and Penstock Full Condition

Force on Anchor Block from u/s side

F_{cus} = Load (1 + 2 + 3 - 5 - 7 + 9 +11)

= 939915.99 + 15853.09 + 0 + 0

= 955769.08 N

Force on Anchor Block from d/s side

F_{cds} = Load (- 1 - 2 + 4 + 6 + 8 - 10 +12)

= - 939915.99 - 15853.09 + 0 + 0

= -955769.09 N

Case 3: Expansion and Penstock Empty Condition

Force on Anchor Block from u/s side

$F_{eus'}$ = Load (3 + 5)

= 0 + 0

= 0 N

Force on Anchor Block from d/s side

$F_{eds'}$ = Load (4 - 6)

= 0 - 0

= 0 N

Case 4: Contraction and Penstock Empty Condition

Force on Anchor Block from u/s side

$F_{cus'}$ = Load (3 - 5)

$= 0 - 0$

$= 0$ N

Force on Anchor Block from d/s side

$F_{cds'}$ = Load (4 + 6)

$= 0 + 0$

$= 0$ N

Here, $F_{eus} = F_{cus}$ and Feds = F_{cds}

So, both **case1** and **case 2** are governing

3.5.4 Bend 5

Bend 5 was provided with combined bend with 135.0 m head of water. Here also expansion joint was provided just after the Anchor Block for d/s side, there for we had considered whole length of pipe load from Anchor Block to expansion joint rather than assume that half load was taken by pier.

Max head at any point including water hammer $(H_d) = H_{net} \times (1 + P_{surge} / 100)$

$= 135 \times (1 + 33 / 100)$

$= 179.55$ m

Friction of expansion joint per meter of circumference

$(f') = 1.5 \times \mu \times w \times e \times H$

$= 1.5 \times 0.26 \times 1000 \times 0.125 \times 179.55$

$= 85867.54$

C/S area of pipe at anchor (A) $= \pi/4 \times D_a^2$

$= \pi/4 \times (1.2)^2$

$= 1.13 \text{ m}^2$

C/S area of pipe above upper reducer (A') $= \pi/4 \times D_u^2$

$= \pi/4 \times (1.2)^2$

$= 1.13 \text{ m}^2$

C/S area of pipe below lower reducer (A") $= \pi/4 \times D_l^{2.}$

$= \pi/4 \times (1.2)^2$

$= 1.13\ m^2$

C/S area of pipeshell at uphill of expansion joint (a) $= \pi \times (t / 1000) \times (d_u + (t / 1000))$

$= \pi \times 0.005 \times (1.2 + 0.005)$

$= 0.019\ m^2$

C/S area of pipeshell at downhill of expansion joint (a') $= \pi \times (t'/ 1000) \times (d_l + (t' / 1000))$

$= \pi \times 0.005 \times (1.1 + 0.005)$

$= 0.019\ m^2$

Design discharge $Q_d = (1+ P_{overload} / 100) \times Q_{inflow}$

$= (1 + 15 / 100) \times 4.77$

$= 5.49\ m^3$

Velocity (V) $= Q_d / A$

$= 5.49 / 1.13$

$= 4.85$ m / sec

Dead weight of pipe from anchor uphill to expansion joint

(P) $= L_{ue} \times a \times \gamma$

$= 53.91 \times 0.019 \times 7.85 \times 10000$

$= 78580.71$ N

Weight of water in pipe P (W) $= L_{ue} \times A' \times w$

$= 53.91 \times 1.13 \times 10 \times 1000$

$= 598124.7$ N

Dead weight of pipe from anchor downhill to expansion joint

(P') $= L_{de} \times a' \times \gamma$

$= 28.93 \times 0.019 \times 7.85 \times 10000$

$= 42169.17$ N

Weight of water in pipe P' (W') $= L_{de} \times A'' \times w$

$= 7.68 \times 1.13 \times 10 \times 1000$

$= 320974.7$ N

Weight of pipe and contained water from anchor to adjacent uphill pier

(p) $= L_{up} / L_{ue} \times (P + W)$

$= 7.5 / 53.91 \times (78580.71 + 598124.7)$

$= 94143.77$ N

Weight of pipe and contained water from anchor to adjacent downhill pier

$(P') = L_{dp} / L_{de} \times (P' + W')$

As such $L_{dp} = 0$

So, $(P') = P' + W'$

$= (42169.17 + 320974.7)$

$= 363143.87$ N

- **Loads and forces acting on anchor block:**

1. Hydrostatic force acting along axis of pipe on each side of bend

   $F_s = w \times A \times H_d$

   $= 10 \times 1000 \times 1.13 \times 179.55$

   $= 1992084.7$ N

2. Dynamic force acting against out - side of bend

   $F_d = Q_d \times w \times V / g$

   $= 5.49 \times 10 \times 1000 \times 4.85 / 9.81$

   $= 26605.97$ N

3. Force due to dead weight of pipe from anchor uphill to expansion joint, tending to slide downhill over pier

   $D_u = P \times \text{Sin}(\alpha_{vu})$

   $= 78580.71 \times \text{Sin } 23.81$

   $= 31723.49$ N

4. Force due to dead weight of pipe from anchor downhill to expansion joint, tending to slide downhill over pier

   $D_d = P' \times \text{Sin}(\alpha_{vd})$

   $= 42169.17 \times \text{Sin}(32.11)$

   $= 22414.92$ N

5. Sliding friction of pipe on piers due to expansion or contraction uphill from anchor

   $S_{pu} = f \times \text{Cos}(\alpha_{vu}) \times (P + W - p / 2)$

   $= 0.5 \times \text{Cos}(23.81) \times (78580.71 + 598124.7 - 94143.77 / 2)$

   $= 288022.33$ N

6. Sliding friction of pipe on piers due to expansion or contraction downhill from anchor

$S_{pd} = f \times Cos(\alpha_{vd}) \times (P' + W' - p' / 2)$

$= 0.5 \times Cos(32.11) \times (42169.17 + 320974.7 - 363143.87 / 2)$

$= 6397.81 \times 0.83 \times (42169.17 + 320974.7 - 363143.87 / 2)$

$= 153796.61$ N

7. Sliding friction of uphill expansion joint

$S_{eu} = f' \times \pi \times (d + 2 \times t)$

$= 85867.54 \times \pi \times (1.2 + 2 \times (0.005))$

$= 326411.38$ N

8. Sliding friction of downhill expansion joint

$S_{ed} = f' \times \pi \times (d + 2 \times t')$

$= 85867.54 \times \pi \times (1.2 + 2 \times (0.005))$

$= 326411.38$ N

9. Hydrostatic pressure on exposed end of pipe in uphill expansion joint

$F_u = w \times a \times H_d$

$= 10 \times 1000 \times 0.019 \times 179.55$

$= 33339.75$ N

10. Hydrostatic pressure on exposed end of pipe in downhill expansion joint

$F_d = w \times a' \times H_d$

$= 10 \times 1000 \times 0.019 \times 179.55$

$= 33339.75$ N

11. Longitudinal force due to reducer above anchor

$L_u = w \times H_d \times (A' - A)$

$= 10 \times 1000 \times 179.55 \times (0)$

$= 0$

12. Longitudinal force due to reducer below anchor

$L_d = w \times H_d \times (A' - A)$

$= 10 \times 1000 \times 179.55 \times (0)$

$= 0$

- **Governing Case:**

Due to high head of water major force was the hydrostatic force. All for conditions for finding governing case was listed below:

Case 1: Expansion and Penstock Full Condition

Force on Anchor Block from u/s side

F_{eus} = Load (1 + 2 + 3 + 5 + 7 + 9 +11)

= 1992084.7 + 26605.96 + 31723.49 + 288022.33 + 326411.38 + 33339.75+ 0

= 2698187.65 N

Force on Anchor Block from d/s side

F_{eds} = Load (- 1 - 2 + 4 - 6 - 8 - 10 +12)

= -1992084.7 - 26605.96+ 22414.92 - 153796.61 - 326411.38 - 33339.75 + 0

= -2509823.52 N

Case 2: Contraction and Penstock Full Condition

Force on Anchor Block from u/s side

F_{cus} = Load (1 + 2 + 3 - 5 - 7 + 9 +11)

= 1992084.7 + 26605.96 + 31723.49 - 288022.33 - 326411.38 + 33339.75 + 0

= 1469320.22 N

Force on Anchor Block from d/s side

F_{cds} = Load (- 1 - 2 + 4 + 6 + 8 - 10 +12)

= -1992084.7 - 26605.96 + 22414.92 + 153796.61 + 326411.38 - 33339.75 + 0

= -1549407.5 N

Case 3: Expansion and Penstock Empty Condition

Force on Anchor Block from u/s side

$F_{eus'}$ = Load (3 + 5)

= 31723.49 + 33445.87

= 65169.36 N

Force on Anchor Block from d/s side

$F_{eds'}$ = Load (4 - 6)

= 22414.92 – 17859.24

= 4555.67 N

Case 4: Contraction and Penstock Empty Condition

Force on Anchor Block from u/s side

$F_{cus'}$ = Load (3 - 5)

= 31723.49 - 33445.87

= -1722.37 N

Force on Anchor Block from d/s side

$F_{cds'}$ = Load (4 + 6)

= 22414.92 + 17859.24

= 47274.16 N

Here, $F_{eus} > F_{cus}$ and Feds < F_{cds}

So, **Case 1** will be the governing case

3.6 Summary of Analysis

Analysis was done to find out the forces on Anchor Block, from which we had the governing condition for the Anchor Block. From analysis we had seen that there was always case 1 was governing case. When high head of water was there, hydrostatic force was the major force. Dead weight of pipe depends upon the length of pipe on that particular side. While sliding friction of pipe on piers were totally depends upon the location of expansion joint. Load (5, 6, 7, 8, 9 10) depends upon the presence of expansion joint. If we are not providing expansion joint than we had both case 1 as well as case 2 were governing. Longitudinal forces depend upon the reducer.

4.1 Introduction

As we know that Anchor Blocks were the massive structure with large volume of concrete, so that needed optimization of an Anchor Block. It was not only optimizing the shape and size of an Anchor block, but it should preferably be founded on a rock base. Wherever rock is available at great depths, the stability of overburden material as excavated for anchor block foundation shall be checked against sliding as an earthen slope with anchor block on it and in its natural condition. Stable slope cuts shall be provided around the anchor block location so as to safeguard against the possibility of a slide of the slope cut damaging the anchor block foundation.

Anchor Block must be check for the following four conditions:

1 There is to be no sliding at any section in the anchor block.
2 There is to be no overturning or rotation of the anchor block.
3 There is to be no tension in any part of the concrete of the block.
4 There is to be no crushing or failure due to compression in the block or at the foundation.

4.2 Checks

Checks on Anchor Block was done to make it safely resist all the loads come from pipes and to make Anchor Block size and shape optimize. For Anchor we had go for four types of checks listed below:

4.2.1 Check for Overturning

Overturning moment was considered at toe of Anchor Block, in which force due to dead weight of block, earth pressure and forces from pipes would be considered.

Safety factor for overturning = Rmy / Omy > 1.2

Rmy = Resisting moment.

Omy = Overturning moment.

Stability of the Anchor Block against overturning may be checked by following criteria:

- The Anchor Block tilts at the toe.
- The weight of the Anchor Block acts at the center of gravity of the Anchor Block.
- As such movement in Anchor Block is not permitted so Earth pressure at Rest is considered.

Forces which are creating Resisting moment.

- Weight of the Anchor Block.
- Horizontal force from down stream pipe.
- Uplift force from the up stream pipe.

Forces which are creating Overturning moment.

- Earth pressure.
- Horizontal force from upstream pipe.
- Uplift force from downstream pipe.

$$Omy = (xP1 \times Y1) + (F_o \times h2) - (yP2 \times X1)$$

$$Rmy = (WT_{blk} \times X2) - (xP2 \times Y1) + (yP1 \times X1)$$

WT_{blk} = Weight of the Anchor Block

xP1 = Force in x – direction from pipe on u/s side

yP1 = Force in y – direction from pipe on u/s side

xP2 = Force in x – direction from pipe on d/s side

yP2 = Force in y – direction from pipe on d/s side

F_o = Force on block due to pressure 'at rest'

h2 = Centroidal distance of force 'F_o' from the base of block

X1 = Distance of pipe intersection to edge of block

Y1 = Distance of pipe intersection from the base of block

X2 = Distance of centroid of anchor block from edge of block

4.2.2 Check for Sliding

Sliding factor depends upon the weight of the block, net horizontal forces from pipes and earth pressure and co-efficient of friction between concrete and soil.

Considering at rest pressure

Since it is assumed that the pipeline is to be relieved of all stresses on account of reckonable forces such as thrust etc. no movement can be allowed in the pipeline and therefore, it would be reasonable to consider forces due to **"at rest pressure"** in place of passive pressures for counteracting unbalance forces. This would mean that active pressure would not be operating on the block.

Safety factor for sliding = $S_r / R_x < 1.5$

$S_r = V_r \times \mu$

S_r = Frictional Resistance offered by the Rock.

V_r = Total vertical load of the block.

μ = Coefficient of friction between concrete and soil.

R_x = Resultant force component in x direction.

- Horizontal force from upstream pipe will decrease the sliding factor.
- Horizontal force from downstream pipe will increase the sliding factor.
- Earth pressure will decrease the sliding factor.

There are occasion where it is impossible to have the sliding factor ≥ 1.5

Increase the weight of the Anchor Block.

4.2.3 Check for Location of Resultant.

This check was done to make sure that at any part of Anchor Block was not under tension. This factor mainly depends upon width of block, forces in vertical direction, resisting and overturning moment.

Resultant must be lie between middle third of the base of the Anchor Block.

Location of the Resultant (x) = (Rmy – Omy)/ V_r

Eccentricity (e) = B/2 – x

e < B/6

There are occasions where it is impossible to have the eccentricity > B/6. In this case

Increase the base dimension of the Anchor block until the eccentricity is e = B/6

4.2.4 Check for Base pressure

This factor mainly depends upon length and width of block, location of resultant and forces in vertical direction. Maximum and minimum base pressure must be under specified limits listed below:

Max Base pressure $q_{max} = (V_r / L \times B) \times (1 + 6 \times e / B)$

q_{max} < SBC of soil

Min Base pressure $q_{min} = (V_r / L \times B) \times (1 + 6 \times e / B)$

$q_{min} > 0$ (no tension)

4.3 Design of Anchor Block

4.3.1 Bend 1

From the results of analysis, case 1 (Expansion and Penstock full condition) was the governing case and made design of Anchor Block for this case.

Design for Case 1, Expansion and Penstock full condition

Force on Anchor Block from Upstream side, P1 = $(F_{eus}/ (1000 \times g))$

= (138722.15 / 1000×g)

= 14.14 tonne

Force on Anchor Block from Downstream side, P2 = $(F_{eds}/ (1000 \times g))$

= (-144925.68/1000×g)

= -14.77 tonne

Soil properties (ϕ) = 28°

Density of concrete = 2.5 t/m^3

Density of soil = 1.8 t/m^3

Coefficient of friction between concrete and soil (μ) = 0.4

Safe bearing capacity of foundation strata (SBC) = 20 t/m^2

self weight of pipe per m length = $\pi \times (d_i + t) \times t \times \gamma$

$= \pi \times (1.2 + 0.005) \times 0.005 \times 7.85$

$= 0.149$ tonne / m

- AB 1

Length of the block (L) = 3 m

Width of the block (B) = 2.4 m

Depth of the block (D) = 3.14 m

Depth of block below ground (D1) = 0.73 m

C/S area of the block (A_b) = 7.536 m^2

Length of the pipe P1 inside the block (a) = 0.99 m

Length of the pipe P2 inside the block (b) = 1.56 m

Distance of pipe intersection to edge of block (X1) = 1.41 m

Distance of centroid of anchor block from edge of block (X2) = 1.20 m

Distance of the pipe intersection from the base of the block (Y1) = 1.93 m

Resolution of forces in two mutually perpendicular direction

$xP1 = P1 \times \cos \alpha_{vu}$

$= 14.14 \times \cos 0$

$= 14.14$ tonne

$yP1 = P1 \times \sin \alpha_{vu}$

$= 14.14 \times \sin 0$

$= 0$

$xP2 = P2 \times \cos \alpha_{vd}$

$= -14.77 \times \cos 19.48$

$= -13.93$ tonne

$yP2 = P2 \times \sin \alpha_{vd}$

$= -14.77 \times \sin 19.48$

$= -4.93$ tonne

First we are assuming that block is of size (L x B x D) **3 x 5 x 5.15** m

Pressure co – efficient

$K_o = 1 - \sin\phi$

$= 1 - \sin 28°$

$= 0.53$

Pressure at the bottom of the block

$p_d = \gamma_s \times K_o \times D$

$= 1.8 \times 0.53 \times 3.14$

$= 3.00$ tonne / m

Force due to 'at rest' soil pressure

$F_o = ½ \times p_d \times D1 \times L$

$= ½ \times 3 \times 0.73 \times 3$

$= 3.28$ tonne

Centroidal distance of force 'F_o' from the base of block

$h2 = ⅓ \times D1$

$= ⅓ \times 0.73$

$= 0.24$ m

Calculation of the weight of the block

Volume of pipe inside the block

$V_p = (\pi/4) \times (d_i + 2 \times t)^2 \times (a + b)$

$= 0.78 \times (1.2 + 2 \times 0.005)^2 \times (0.99 + 1.56)$

$= 2.93\ m^3$

Net volume of the block

$V_{blk} = A \times L - V_p$

$= 7.536 \times 3 - 2.93$

$= 19.68\ m^3$

Weight of the block (excluding pipe)

$W_{blk} = V_{blk} \times D_c$

$= 19.68 \times 2.5$

$= 49.19$ tonne

Weight of water in pipe

$W_{wtr} = (\pi/4) \times d_i^2 \times (a + b + L_{up}/2 + L_{de})$

$= 0.78 \times 1.2^2 \times (0.99 + 1.56 + 2 / 2 + 5)$

$= 9.67$ tonne

Weight of pipe

$W_{pipe} = W_{sp} \times (a + b + L_{up} / 2 + L_{de})$

$= 0.149 \times (0.99 + 1.56 + 2 / 2 + 5)$

$= 1.27$ tonne

So, total weight of the block

$WT_{blk} = W_{blk} + W_{wtr} + W_{pipe}$

$= 49.19 + 9.67 + 1.27 = 60.13$ tonne

Calculation of overturning moment about toe of anchor block:

$Omy = (xP1 \times Y1) + (F_o \times h2) - (yP2 \times X1)$

$= (14.14 \times 1.93) + (3.28 \times 0.24) – ((-4.93) \times 1.41)$

$= 35.04$ tonne.m

Resisting moment about toe of anchor block

$Rmy = (WT_{blk} \times X2) - (xP2 \times Y1) + (yP1 \times X1)$

$= (60.13 \times 1.20) – ((-13.93) \times 1.93) + (0)$

$= 99.04$ tonne.m

F.O.S against overturning

F.O.S = Rmy / Omy

$= 99.04 / 35.04$

$= 2.83 > 1.2$

Hence, O.K.

Check for location of the resultant

Total vertical reaction

$V_r = WT_{blk} + yP1 + yP2$

$= 60.13 + 0 – 4.93$

$= 55.21$ tonne

$x = (Rmy – Omy) / V_r$

$= (99.04 – 35.04) / 55.21$

$= 1.16$ m

Eccentricity

$e = (B/2) – x$

$= (2.4/2) – 1.16$

$= 0.04$ m

Hence, O.K.

Middle third of the base = B / 6

$= 2.4 / 6$

$= 0.4$ m > e

Hence O.K.

Check for sliding:

Resultant force component in x – direction

$Rx = xP1 + Xp2 + F_o$

$= 14.14 – 13.93 + 3.28$

$= 3.50$ tonne

Total vertical load of the block

$V_r = 55.21$ tonne

Frictional resistance offered by the rock

$Sr = V_r \times \mu$

$= 55.21 \times 0.4$

$= 22.08$ tonne

F.O.S against sliding

F.O.S. $= S_r / R_x$

$= 22.08 / 3.50$

$= 6.32 > 1.5$

Hence O.K.

Check for base pressure:

Max base pressure

$q_{max} = (V_r / (L \times B)) \times (1 + (6 \times e / B))$

$= (55.21 / (3 \times 2.4)) \times (1 + (6 \times 0.04 / 2.4))$

$= 8.45$ tonne / m^2

$q_{min} = (V_r / (L \times B)) \times (1 - (6 \times e / B))$

$= (55.21 / (3 \times 2.4)) \times (1 - (6 \times 0.04 / 2.4))$

$= 6.89$ tonne / m^2

qmax > S.B.C.

qmin > 0

Hence no tension

From above result we had max base pressure more than S.B.C., it is more preferable to decrease depth of anchor block rather than decreasing width or length of block to make it optimize.

- AB 2

Length of the block (L) = 3 m

Width of the block (B) = 2.15 m

Depth of the block (D) = 2.88 m

Depth of block below ground (D1) = 0.61 m

C/S area of the block (A_b) = 6.192 m^2

Length of the pipe P1 inside the block (a) = 0.99 m

Length of the pipe P2 inside the block (b) = 1.28 m

Distance of pipe intersection to edge of block (X1) = 1.17 m

Distance of centroid of anchor block from edge of block (X2) = 1.14 m

Distance of the pipe intersection from the base of the block (Y1) = 1.59 m

So for different dimension for the anchor block we had the following results:

Anchor Block No.	L	B	D	Weight	Over turning factor	Location of resultant	Sliding factor	q_{max}	q_{min}
AB 1	3	2.4	3.14	60.13	2.8	0.1	4.24	9.67	5.84
AB 2	3	2.15	2.88	50.52	2.74	0.02	4.11	7.51	6.82
AB 3	3	2.4	2.94	56.56	2.78	0.04	4.14	7.98	6.54
AB 4	3	2.4	2.58	50.05	2.44	0.13	3.91	8.4	4.31
AB 5	3	1.95	2.83	45.82	2.37	0.03	3.73	7.79	6.41
AB 6	3	1.7	2.79	40.41	2.02	0.08	3.74	9.03	5.13
AB 7	3	1.5	2.75	36.11	1.81	0.09	3.5	9.51	4.63
AB 8	**3**	**1.3**	**2.75**	**32.34**	**1.6**	**0.1**	**3.08**	**10.53**	**3.85**

Table 4.1 Results for different types of shape for Bend 1

Here as such forces were of less amount of magnitude, all the trial were safe but AB 8 had lesser compare to all, so we were adopting optimum shape as AB 8. calculation of which were as follows:

4.3.2 Bend 2

From the results of analysis, case 1 (Expansion and Penstock full condition) was the governing case and made design of Anchor Block for this case.

Design for Case 1, Expansion and Penstock full condition

Force on Anchor Block from Upstream side, P1 = $(F_{eus} / (1000 \times g))$

$= (2234243.27 / 1000 \times g)$

$= 222.57$ tonne

Force on Anchor Block from Downstream side, P2 = $(F_{eds} / (1000 \times g))$

$= (-1549009.75/1000 \times g)$

$= -157.90$ tonne

Soil properties (ϕ) = 28°

Density of concrete = 2.5 t/m^3

Density of soil = 1.8 t/m^3

Coefficient of friction between concrete and soil (μ) = 0.4

Safe bearing capacity of foundation strata (SBC) = 20 t/m^2

self weight of pipe per m length = $\pi \times (d_i + t) \times t \times \gamma$

$= \pi \times (1.2 + 0.005) \times 0.005 \times 7.85$

$= 0.149$ tonne / m

- AB 1

Length of the block (L) = 3 m

Width of the block (B) = 5 m

Depth of the block (D) = 5.15 m

Depth of block below ground (D1) = 2.422 m

C/S area of the block (A_b) = 25.74 m^2

Length of the pipe P1 inside the block (a) = 3.11 m

Length of the pipe P2 inside the block (b) = 2.57 m

Distance of pipe intersection to edge of block (X1) = 2.5 m

Distance of centroid of anchor block from edge of block (X2) = 2.49 m

Distance of the pipe intersection from the base of the block (Y1) = 1.945 m

Resolution of forces in two mutually perpendicular direction

$xP1 = P1 \times \text{Cos}\ \alpha_{vu}$

$= 222.57 \times \text{Cos}\ 36.43$

$= 182.68$ tonne

$yP1 = P1 \times \text{Sin}\ \alpha_{vu}$

$= 222.57 \times \text{Sin}\ 36.43$

$= 136.01$ tonne

$xP2 = P2 \times \text{Cos}\ \alpha_{vd}$

$= -157.90 \times \text{Cos}\ 36.43$

$= -153.38$ tonne

$yP2 = P2 \times \text{Sin}\ \alpha_{vd}$

$= -157.90 \times \text{Sin}\ 36.43$

$= -37.53$ tonne

First we are assuming that block is of size (L x B x D) **3 x 5 x 5.15** m

Pressure co – efficient

$K_o = 1 - \text{Sin}\ \phi$

$= 1 - \text{Sin}\ 28°$

$= 0.53$

Pressure at the bottom of the block

$p_d = \gamma_s \times K_o \times D$

$= 1.8 \times 0.53 \times 5.15$

$= 4.92$ tonne / m

Force due to 'at rest' soil pressure

$F_o = ½ \times p_d \times D1 \times L$

$= ½ \times 4.92 \times 2.42 \times 3$

$= 17.86$ tonne

Centroidal distance of force 'F_o' from the base of block

$h2 = ⅓ \times D1$

$= \frac{1}{3} \times 2.42$

$= 0.81$ m

Calculation of the weight of the block

Volume of pipe inside the block

$V_p = (\pi/4) \times (d_i + 2 \times t)^2 \times (a + b)$

$= 0.78 \times (1.2 + 2 \times 0.005)^2 \times (3.11 + 2.57)$

$= 6.53\ m^3$

Net volume of the block

$V_{blk} = A \times L - V_p$

$= 25.74 \times 3 - 6.53$

$= 70.69\ m^3$

Weight of the block (excluding pipe)

$W_{blk} = V_{blk} \times D_c$

$= 70.69 \times 2.5$

$= 176.72$ tonne

Weight of water in pipe

$W_{wtr} = (\pi/4) \times d_i^2 \times (a + b + L_{up}/2 + L_{de})$

$= 0.78 \times 1.2^2 \times (3.11 + 2.57 + 7.5 / 2 + 5)$

$= 16.32$ tonne

Weight of pipe

$W_{pipe} = W_{sp} \times (a + b + L_{up} / 2 + L_{de})$

$= 0.149 \times (3.11 + 2.57 + 7.5 / 2 + 5)$

$= 2.15$ tonne

So, total weight of the block

$WT_{blk} = W_{blk} + W_{wtr} + W_{pipe}$

$= 176.72 + 16.32 + 2.15 = 195.19$ tonne

Calculation of overturning moment about toe of anchor block:

$Omy = (xP1 \times Y1) + (F_o \times h2) - (yP2 \times X1)$

$= (182.68 \times 1.94) + (17.86 \times 0.81) - ((-37.53) \times 2.5)$

$= 463.56$ tonne.m

Resisting moment about toe of anchor block

$Rmy = (WT_{blk} \times X2) - (xP2 \times Y1) + (yP1 \times X1)$

$= (195.19 \times 2.49) - ((-153.38) \times 1.94) + (136.01 \times 2.5)$

$= 1124.37$ tonne.m

F.O.S against overturning

F.O.S = Rmy / Omy

$= 1124.37 / 463.56$

$= 2.43 > 1.2$

Hence, O.K.

Check for location of the resultant

Total vertical reaction

$V_r = WT_{blk} + yP1 + yP2$

$= 195.19 + 136.01 - 37.53$

$= 293.67$ tonne

$x = (Rmy - Omy) / V_r$

$= (1124.37 - 463.56) / 293.67$

$= 2.25$ m

Eccentricity

$e = (B/2) - x$

$= (5/2) - 2.25$

$= 0.25 \text{ m} < 2.25$

Hence, O.K.

Middle third of the base = B / 6

$= 5 / 6$

$= 0.83 \text{ m} > e$

Hence O.K.

Check for sliding:

Resultant force component in x – direction

$Rx = xP1 + Xp2 + F_o$

= 182.68 – 153.38 + 17.86

= 47.16 tonne

Total vertical load of the block

V_r = 293.67 tonne

Frictional resistance offered by the rock

$Sr = V_r \times \mu$

$= 293.67 \times 0.4$

= 117.47 tonne

F.O.S against sliding

F.O.S. = S_r / R_x

= 117.47 / 47.16

= 2.49 > 1.5

Hence O.K.

Check for base pressure:

Max base pressure

$q_{max} = (V_r / (L \times B)) \times (1 + (6 \times e / B))$

$= (293.67 / (3 \times 5)) \times (1 + (6 \times 0.25 / 5))$

= 25.45 tonne / m^2

$q_{min} = (V_r / (L \times B)) \times (1 - (6 \times e / B))$

$= (293.67 / (3 \times 5)) \times (1 - (6 \times 0.25 / 5))$

= 13.71 tonne / m^2

qmax > S.B.C.

qmin > 0

Hence no tension

From above result we had max base pressure more than S.B.C., it is more preferable to decrease depth of anchor block rather than decreasing width or length of block to make it optimize.

- AB 2

Length of the block (L) = 3 m

Width of the block (B) = 5 m

Depth of the block (D) = 4.45 m

Depth of block below ground (D1) = 2.28 m

C/S area of the block (A_b) = 22.25 m^2

Length of the pipe P1 inside the block (a) = 2.21 m

Length of the pipe P2 inside the block (b) = 2.57 m

Distance of pipe intersection to edge of block (X1) = 2.5 m

Distance of centroid of anchor block from edge of block (X2) = 2.38 m

Distance of the pipe intersection from the base of the block (Y1) = 1.945 m

So for different dimension for the anchor block we had the following results:

Anchor Block No.	L	B	D	Weight	Over turning factor	Location of resultant	Sliding factor	q_{max}	q_{min}
AB 1	3	5	5.15	195.19	2.43	0.25	2.49	**25.45**	13.71
AB 2	3	5	3.95	170.45	2.27	0.33	2.45	**25.01**	10.85
AB 3	3	5	3.47	133.70	2.12	0.29	2.29	**20.93**	10.03
AB 4	3	5	3.33	128.45	2.17	0.28	2.30	**20.14**	10.12
AB 5	3	5	3.07	118.73	2.15	0.22	2.29	18.25	10.71
AB 6	3	5	2.53	98.64	1.98	0.38	2.17	19.07	7.21
AB 7	3	4.5	2.54	90.31	1.78	0.57	2.07	**24.58**	3.39
AB 8	4.3	4.5	2.54	127.45	1.95	0.53	2.29	19.92	3.43
AB 9	3	4.2	2.51	83.82	1.83	0.70	2.09	**22.35**	5.16
AB 10	**2.8**	**5**	**2.53**	**92.32**	**1.95**	**0.38**	**2.13**	**19.86**	**7.39**

Table 4.2 Results for different types of shape for convex type bend

In Table 4.2, red color indicated that particular checks exceeds than required and results with blue color indicate that result gives optimum size and shape of Anchor Block. We can see from the result AB 9 having lesser weight among all, but qmax > S.B.C. of soil, again for AB 7 qmax > S.B.C., so most optimized is **AB 10** in which all our conditions are in specified limits. Calculation of which were as follows:

4.3.3 Bend 3

From the result of analysis we had case 1 was the governing case and done design for the same case.

Design for Case 1, Expansion and Penstock full condition

Force on Anchor Block from Upstream side, P1 = $(F_{eus}/ (1000 \times g))$

$= (2294522.60/ 1000 \times g)$

$= 233.90$ tonne

Force on Anchor Block from Downstream side, P2 = $(F_{eds}/ (1000 \times g))$

$= (-1544245.18/1000 \times g)$

$= -157.42$ tonne

Soil properties (ϕ) = 28°

Density of concrete = 2.5 t/m^3

Density of soil = 1.8 t/m^3

Coefficient of friction between concrete and soil (μ) = 0.4

Safe bearing capacity of foundation strata (SBC) = 20 t/m^2

self weight of pipe per m length = $\pi \times (d_i + t) \times t \times \gamma$

$= \pi \times (1.2 + 0.005) \times 0.005 \times 7.85$

$= 0.149$ tonne / m

- AB 1

Length of the block (L) = 3 m

Width of the block (B) = 5 m

Depth of the block (D) = 6 m

Depth of block below ground (D1) = 3.54 m

C/S area of the block (A_b) = 30 m^2

Length of the pipe P1 inside the block (a) = 2.62 m

Length of the pipe P2 inside the block (b) = 3.02 m

Distance of pipe intersection to edge of block (X1) = 2.50 m

Distance of centroid of anchor block from edge of block (X2) = 2.50 m

Distance of the pipe intersection from the base of the block (Y1) = 4.02 m

Resolution of forces in two mutually perpendicular direction

$xP1 = P1 \times \text{Cos } \alpha_{vu}$

$= 233.90 \times \text{Cos } 16.7$

$= 224.13$ tonne

$yP1 = P1 \times \text{Sin } \alpha_{vu}$

$= 233.90 \times \text{Sin } 16.70$

$= 66.88$ tonne

$xP2 = P2 \times \text{Cos } \alpha_{vd}$

$= -157.42 \times \text{Cos } 34.22$

$= -129.92$ tonne

$yP2 = P2 \times \text{Sin } \alpha_{vd}$

$= -157.42 \times \text{Sin } 34.22$

$= -129.92$ tonne

First we are assuming that block is of size (L x B x D) **3 x 5 x 6** m

Pressure co – efficient

$K_o = 1 - \text{Sin } \phi$

$= 1 - \text{Sin } 28°$

$= 0.53$

Pressure at the bottom of the block

$p_d = \gamma_s \times K_o \times D$

$= 1.8 \times 0.53 \times 6$

$= 5.73$ tonne / m

Force due to 'at rest' soil pressure

$F_o = ½ \times p_d \times D1 \times L$

$= ½ \times 5.73 \times 3.54 \times 3$

$= 30.42$ tonne

Centroidal distance of force 'F_o' from the base of block

$h2 = ⅓ \times D1$

$= ⅓ \times 3.54$

$= 1.18$ m

Calculation of the weight of the block

Volume of pipe inside the block

$V_p = (\pi/4) \times (d_i + 2 \times t)^2 \times (a + b)$

$= 0.78 \times (1.2 + 2 \times 0.005)^2 \times (2.62 + 3.02)$

$= 6.49\ m^3$

Net volume of the block

$V_{blk} = A \times L - V_p$

$= 30 \times 3 - 6.49$

$= 83.51\ m^3$

Weight of the block (excluding pipe)

$W_{blk} = V_{blk} \times D_c$

$= 83.51 \times 2.5$

$= 208.79$ tonne

Weight of water in pipe

$W_{wtr} = (\pi/4) \times d_i^2 \times (a + b + L_{up}/2 + L_{de})$

$= 0.78 \times 1.2^2 \times (2.62 + 3.02 + 7.5 / 2 + 5)$

$= 16.27$ tonne

Weight of pipe

$W_{pipe} = W_{sp} \times (a + b + L_{up} / 2 + L_{de})$

$= 0.149 \times (2.62 + 3.02 + 7.5 / 2 + 5)$

$= 2.14$ tonne

So, total weight of the block =

$WT_{blk} = W_{blk} + W_{wtr} + W_{pipe}$

$= 208.79 + 16.27 + 2.14$

$= 227.21$ tonne

Calculation of overturning moment about toe of anchor block:

$Omy = (xP1 \times Y1) + (F_o \times h2) - (yP2 \times X1)$

$= (224.13 \times 4.05) + (30.42 \times 1.18) – ((-88.88) \times 2.5)$

$= 1165.83$

Resisting moment about toe of anchor block

$Rmy = (WT_{blk} \times X2) - (xP2 \times Y1) + (yP1 \times X1)$

$= (227.21 \times 2.5) – ((-129.92) \times 4.05) + (66.88 \times 2.5)$

$= 1261.40$ tonne.m

F.O.S against overturning

F.O.S = Rmy / Omy

$= 1261.40 / 1165.83$

$= 1.08 < 1.2$

Hence, not O.K.

Check for location of the resultant:

Total vertical reaction

$V_r = WT_{blk} + yP1 + yP2$

$= 227.21 + 66.88 – 88.88$

$= 205.20$ tonne

$x = (Rmy – Omy) / V_r$

$= (1261.40 – 1165.83) / 205.20$

$= 2.03$ m

Eccentricity

$e = (B/2) – x$

$= (5/2) – 2.25$

$= 0.25$ m

Middle third of the base = B / 6

$= 5 / 6$

$= 0.83 \text{ m} < e$

Hence, not O.K.

Check for sliding:

Resultant force component in x – direction

$Rx = xP1 + Xp2 + F_o$

$= 224.13 - 129.92 + 30.42$

$= 124.63$ tonne

Total vertical load of the block

$V_r = 205.20$ tonne

Frictional resistance offered by the rock

$Sr = V_r \times \mu$

$= 205.20 \times 0.4$

$= 82.08$ tonne

F.O.S against sliding

$F.O.S. = S_r / R_x$

$= 82.08 / 124.63$

$= 0.66 < 1.5$

Hence, not O.K.

Check for base pressure:

Max base pressure

$q_{max} = (V_r / (L \times B)) \times (1 + (6 \times e / B))$

$= (205.20 / (3 \times 5)) \times (1 + (6 \times 2.03 / 5))$

$= 47.08$ tonne / m^2

$q_{min} = (V_r / (L \times B)) \times (1 - (6 \times e / B))$

$= (205.20 / (3 \times 5)) \times (1 - (6 \times 2.03 / 5))$

$= 19.72$ tonne / m^2

qmax > S.B.C.

qmin < 0

Hence, tension in block.

From above result we can see all our condition were not in specified limits and also resultant is not in middle third of base which create tension so first we go for increasing width of block.

- AB 2

Length of the block (L) = 3 m

Width of the block (B) = 6 m

Depth of the block (D) = 6 m

Depth of block below ground (D1) = 3.54 m

C/S area of the block (A_b) = 36 m^2

Length of the pipe P1 inside the block (a) = 3.14 m

Length of the pipe P2 inside the block (b) = 3.63 m

Distance of pipe intersection to edge of block (X1) = 3 m

Distance of centroid of anchor block from edge of block (X2) = 3 m

Distance of the pipe intersection from the base of the block (Y1) = 3.87 m

So for different dimension for the anchor block we had the following results:

Anchor Block No.	L	B	D	Weight	Over turning factor	Location of resultant	Sliding factor	q_{max}	q_{min}
AB 1	3	5	6	227.21	**1.08**	**2.02**	**0.66**	**46.85**	**-19.49**
AB 2	3	6	6	270.40	1.29	**1.61**	**0.8**	**36.05**	**-8.45**
AB 3	4	6	6	360.42	1.51	**1.22**	**1**	**31.29**	**-3.08**
AB 4	4	7	6	523.63	2.12	**0.82**	**1.39**	**24.37**	4.29
AB 5	5.5	7	4.75	455.82	2.01	**0.68**	**1.25**	17.87	4.67
AB 6	**5.5**	**8**	**5.17**	**565.51**	**2.49**	**0.45**	**1.52**	**16.48**	**8.23**
AB 7	6.75	7	5.02	591.62	2.41	0.48	1.50	17.02	7.09
AB 8	6.1	7.5	5.16	587.90	2.46	0.48	1.51	17.08	7.66

Table 4.3 Results for different types of shape for convex type bend

As such above AB 6 in Table 4.3 all the block having lesser weight but resultant was not lying in middle third of the base and also sliding factor was not in limit. But for AB 6 all the results are in specified limits so it was the optimum shape.

4.2.4 Bend 4

From the results of analysis here case 1 as well as case 2 both were governing cases, as we were not providing expansion joint.

Design for Case 1or Case 2, Expansion or Contraction and Penstock full condition

Force on Anchor Block from Upstream side, P1 = (Feus/ (1000 $\times$ g))

= (971567.33/ 1000 $\times$ g)

= 99.04 tonne

Force on Anchor Block from Downstream side, P2 = (Feds/ (1000 $\times$ g))

= (-971567.33/1000 $\times$ g)

= -99.04 tonne

Soil properties (ϕ) = 28°

Density of concrete = 2.5 t/m^3

Density of soil = 1.8 t/m^3

Coefficient of friction between concrete and soil (μ) = 0.4

Safe bearing capacity of foundation strata (SBC) = 20 t/m^2

Self weight of pipe per m length = $\pi \times (d_i + t) \times t \times \gamma$

$= \pi \times (1.1 + 0.01) \times 0.01 \times 7.85$

= 0.276 tonne / m

- AB 1

Length of the block (L) = 8.24 m

Width of the block (B) = 8.94 m

Depth of the block (D) = 6 m

Depth of block below ground (D1) = 3.39 m

C/S area of the block (A_b) = 53.64 m^2

Length of the pipe P1 inside the block (a) = 4.53 m

Length of the pipe P2 inside the block (b) = 4.27 m

Length between cg of block from the point of rotation along resultant R (X1) = 4.58 m

Distance of pipe intersection to edge of block (X1) = 4 m

Distance of the pipe intersection from the base of the block (Y1) = 3 m

Resolution of forces in two mutually perpendicular direction

$xP1 = P1 \times \cos \alpha_{vu} \times \cos \alpha_{hu}$

$= 99.04 \times \cos 0 \times \cos 45$

$= 70.03$ tonne

$yP1 = P1 \times \sin \alpha_{vu}$

$= 99.04 \times \sin 0$

$= 0$

$zP1 = P1 \times \cos \alpha_{vu} \times \sin \alpha_{hu}$

$= 99.04 \times \cos 0 \times \sin 45$

$= 70.03$ tonne

$xP2 = P2 \times \cos \alpha_{vd} \times \cos \alpha_{hd}$

$= -99.04 \times \cos 0 \times \cos 0$

$= -99.04$ tonne

$yP2 = P2 \times \sin \alpha_{vd}$

$= -99.04 \times \sin 0$

$= 0$

$zP2 = P2 \times \cos \alpha_{vd} \times \sin \alpha_{hd}$

$= -99.04 \times \cos 0 \times \sin 0$

$= 0$

First we are assuming that block is of size (L x B x D) **3 x 5 x 6** m

Force in X – direction

$Fx = xP1 + xP2$

$= 70.03 – 99.03$

$= -29.1$ tonne

Force in Z – direction

$Fz = zP1 + zP2$

$= 70.03 + 0$

$= 70.03$ tonne

$R = (Fx^2 + Fz^2)^{0.5}$

$= 75.80$ tonne

Pressure co – efficient

$K_o = 1 - \sin \phi$

$= 1 - \sin 28°$

$= 0.53$

Pressure at the bottom of the block

$p_d = \gamma_s \times K_o \times D$

$= 1.8 \times 0.53 \times 6$

$= 5.73$ tonne / m

Force due to 'at rest' soil pressure

$F_o = ½ \times p_d \times D1 \times L$

$= ½ \times 5.73 \times 3.39 \times 8.94$

$= 86.82$ tonne

Centroidal distance of force 'F_o' from the base of block

$h2 = ⅓ \times D1$

$= ⅓ \times 3.39$

$= 1.13$ m

Calculation of the weight of the block

Volume of pipe inside the block

$V_p = (\pi/4) \times (d_i + 2 \times t)^2 \times (a + b)$

$= 0.78 \times (1.1 + 2 \times 0.01)^2 \times (4.53 + 4.27)$

$= 8.67\ m^3$

Net volume of the block

$V_{blk} = A \times L - V_p$

$= 53.64 \times 8.24 - 8.67$

$= 433.32\ m^3$

Weight of the block (excluding pipe)

$W_{blk} = V_{blk} \times D_c$

$= 433.32 \times 2.5$

$= 1083.31$ tonne

Weight of water in pipe

$W_{wtr} = (\pi/4) \times d_i^2 \times (a + b + L_{up}/2 + L_{de})$

$= 0.78 \times 1.1^2 \times (4.53 + 4.27 + 4.95 / 2 + 7.68)$

$= 20.37$ tonne

Weight of pipe

$W_{pipe} = W_{sp} \times (a + b + L_{up} / 2 + L_{de})$

$= 0.276 \times (4.53 + 4.27 + 4.95 / 2 + 7.68)$

$= 5.91$ tonne

So, total weight of the block =

$WT_{blk} = W_{blk} + W_{wtr} + W_{pipe}$

$= 1083.31 + 20.37 + 5.91$

$= 1109.59$ tonne

Calculation of overturning moment about toe of anchor block

$Omy = (R \times y1) + (F_o \times h2) - (yP2 \times X1)$

$= (75.80 \times 3) + (86.82 \times 1.13) – ((0) \times 4)$

$= 325.50$ tonne.m

Resisting moment about toe of anchor block

$Rmy = (WT_{blk} \times Lw_{blk}) + (yP1 \times X1)$

$= (1109.59 \times 4.58) – ((0) \times 4)$

$= 5081.92$ tonne.m

F.O.S against overturning

F.O.S = Rmy / Omy

$= 5081.92 / 325.50$

$= 15.61 > 1.2$

Hence, O.K.

Check for location of the resultant

Total vertical reaction

$V_r = WT_{blk} + yP1 + yP2$

$= 1109.59 + 0 + 0$

$= 1109.59$ tonne

$x = (Rmy – Omy) / V_r$

$= (5081.92 – 325.50) / 1109.59$

$= 4.29$ m

Eccentricity

$e = (B/2) – x$

$= (8.94/2) – 4.29$

$= 0.18$ m

Middle third of the base = B / 6

= 8.94 / 6

= 1.49 m > e

Hence, O.K.

Check for sliding

Resultant force component in x – direction

$Rx = xP1 + Xp2 + F_o$

$= 70.03 – 99.03 + 86.82$

$= 90.81$ tonne

Total vertical load of the block

$V_r = 1109.59$ tonne

Frictional resistance offered by the rock

$Sr = V_r \times \mu$

$= 1109.59 \times 0.4$

$= 443.84$ tonne

F.O.S against sliding

F.O.S. = S_r / R_x

= 443.84 / 90.81

= 4.89 > 1.5

Hence, O.K.

Check for base pressure

Max base pressure

$q_{max} = (V_r / (L \times B)) \times (1 + (6 \times e / B))$

$= (1109.59 / (8.24 \times 8.94)) \times (1 + (6 \times 0.18 / 8.94))$

= 16.82 tonne / m^2

$q_{min} = (V_r / (L \times B)) \times (1 - (6 \times e / B))$

$= (1109.59 / (8.24 \times 8.94)) \times (1 + (6 \times 0.18 / 8.94))$

= 13.21 tonne / m^2

qmax < S.B.C.

qmin > 0

Hence, O.K.

From above result we can see all our conditions were in specified limits, so first we go for decreasing width of block.

- AB 2

Length of the block (L) = 8.24 m

Width of the block (B) = 7.84 m

Depth of the block (D) = 6 m

Depth of block below ground (D1) = 3.39 m

C/S area of the block (A_b) = 47.04 m^2

Length of the pipe P1 inside the block (a) = 4.50 m

Length of the pipe P2 inside the block (b) = 4.30 m

Length between cg of block from the point of rotation along resultant R (X1) = 3.84 m

Distance of pipe intersection to edge of block (X1) = 4.03 m

Distance of the pipe intersection from the base of the block (Y1) = 3.01 m

So for different dimension for the anchor block we can have the following results:

Anchor Block No.	L	B	D	Weight (tonne)	Over turning factor	Location of resultant	Sliding factor	q_{max}	q_{min}
AB 1	8.24	8.94	6	1109.6	15.79	0.18	4.92	16.88	13.24
AB 2	8.24	7.84	6	973.63	11.90	0.40	4.61	19.72	10.43
AB 3	7.25	7.84	6	855.98	12.16	0.04	4.32	15.50	14.62
AB 4	7.25	5.7	6	625.84	6.81	0.09	3.16	16.51	13.77
AB 5	6.26	5.7	6	542.43	5.90	0.34	2.98	**20.68**	9.73
AB 6	6.26	5.7	5.42	490.69	5.43	0.39	2.74	19.34	8.17
AB 7	6.26	5.7	4.92	446.09	5.25	0.41	2.54	17.83	7.17
AB 8	5.28	5.7	4.92	378.69	5.24	0.45	2.16	19.83	5.34
AB 9	5.28	4.63	4.92	309.20	3.78	0.42	1.76	19.61	5.69
AB 10	5.28	4.63	4.32	272.53	3.37	0.51	1.55	18.47	3.82
AB 11	5.28	4.63	4.12	260.31	3.54	0.47	**1.47**	17.15	4.15
AB 12	4.87	4.63	4.30	251.45	3.06	0.63	**1.43**	**20.20**	2.10
AB 13	5.28	4.41	4.32	259.99	3.07	0.56	**1.48**	19.68	2.65
AB 14	5.28	4.46	4.32	262.84	3.24	0.47	**1.49**	18.18	4.14
AB 15	**5.28**	**4.51**	**4.32**	**265.69**	**3.41**	**0.38**	**1.51**	**16.72**	**5.59**

Table 4.4 Results for different types of shape for horizontal type bend

From Table 4.4 AB11, 12, 13, 14 had lesser weight than AB 15 but fail due to sliding, therefore we had increase the weight of block, gives optimized shape and size of AB 15. Results of which were as follows:

4.2.5 Bend 5

From the results of analysis, we had case 1 (Expansion and Penstock full condition) was governing and done design for the same.

Design for Case 1,

Force on Anchor Block from Upstream side, P1 = (F_{eus}/ (1000 × g))

= (2698187.65/ 1000 × g)

= 275.04 tonne

Force on Anchor Block from Downstream side, P2 = (F_{eds}/ (1000 × g))

= (-2432925.21/1000 × g)

= -248.0 tonne

Soil properties (ϕ) = 28°

Density of concrete = 2.5 t/m^3

Density of soil = 1.8 t/m^3

Coefficient of friction between concrete and soil (μ) = 0.4

Safe bearing capacity of foundation strata (SBC) = 20 t/m^2

Self weight of pipe per m length = $\pi \times (d_i + t) \times t \times \gamma$

$= \pi \times (1.2 + 0.005) \times 0.005 \times 7.85$

= 0.149 tonne / m

- AB 1

Length of the block (L) = 7.34 m

Width of the block (B) = 7.17 m

Depth of the block (D) = 8 m

Depth of block below ground (D1) = 5.29 m

C/S area of the block (A_b) = 58.72 m^2

Length of the pipe P1 inside the block (a) = 4.16 m

Length of the pipe P2 inside the block (b) = 4.88 m

Length between cg of block from the point of rotation along resultant R (X1) = 3.72 m

Distance of pipe intersection to edge of block (X1) = 3.5 m

Distance of the pipe intersection from the base of the block (Y1) = 4.37 m

Resolution of forces in two mutually perpendicular direction

$xP1 = P1 \times \text{Cos } \alpha_{vu} \times \text{Cos } \alpha_{hu}$

$= 275.04 \times \text{Cos } 23.81 \times \text{Cos } 0$

$= 251.64$ tonne

$yP1 = P1 \times \text{Sin } \alpha_{vu}$

$= 275.04 \times \text{Sin } 23.81$

$= 111.04$

$zP1 = P1 \times \text{Cos } \alpha_{vu} \times \text{Sin } \alpha_{hu}$

$= 275.04 \times \text{Cos } 23.81 \times \text{Sin } 0$

$= 0$

$xP2 = P2 \times \text{Cos } \alpha_{vd} \times \text{Cos } \alpha_{hd}$

$= -248 \times \text{Cos } 32.11 \times \text{Cos } 24.36$

$= -191.37$ tonne

$yP2 = P2 \times \text{Sin } \alpha_{vd}$

$= -248 \times \text{Sin } 32.11$

$= -131.83$ tonne

$zP2 = P2 \times \text{Cos } \alpha_{vd} \times \text{Sin } \alpha_{hd}$

$= -248 \times \text{Cos } 32.11 \times \text{Sin } 24.36$

$= -86.65$ tonne

Force in X – direction

$Fx = xP1 + xP2$

$= 251.64 - 191.37$

$= -60.27$ tonne

Force in Z – direction

$Fz = zP1 + zP2$

$= 0 - 86.65$

$= -86.65$ tonne

$R = (Fx^2 + Fz^2)^{0.5}$

$= 105.55$ tonne

Pressure co – efficient

$K_o = 1 - \text{Sin}\ \phi$

$= 1 - \text{Sin}\ 28°$

$= 0.53$

Pressure at the bottom of the block

$p_d = \gamma_s \times K_o \times D$

$= 1.8 \times 0.53 \times 8$

$= 7.64$ tonne / m

Force due to 'at rest' soil pressure

$F_o = ½ \times p_d \times D1 \times B$

$= ½ \times 7.64 \times 5.29 \times 7.17$

$= 144.88$ tonne

Centroidal distance of force 'F_o' from the base of block

$h2 = ⅓ \times D1$

$= ⅓ \times 5.29$

$= 1.76$ m

Calculation of the weight of the block

Volume of pipe inside the block

$V_p = (\pi/4) \times (d_i + 2 \times t)^2 \times (a + b)$

$= 0.78 \times (1.2 + 2 \times 0.005)^2 \times (4.16 + 4.88)$

$= 10.40 m^3$

Net volume of the block

$V_{blk} = A \times B - V_p$

$= 58.72 \times 7.17 - 10.40$

$= 410.63\ m^3$

Weight of the block (excluding pipe)

$W_{blk} = V_{blk} \times D_c$

$= 410.63 \times 2.5$

$= 1026.57$ tonne

Weight of water in pipe

$W_{wtr} = (\pi/4) \times d_i^2 \times (a + b + L_{up}/2 + L_{de})$

$= 0.78 \times 1.1^2 \times (4.16 + 4.88 + 7.5 / 2 + 28.93)$

$= 47.18$ tonne

Weight of pipe

$W_{pipe} = W_{sp} \times (a + b + L_{up} / 2 + L_{de})$

$= 0.149 \times (4.16 + 4.88 + 7.5 / 2 + 28.93)$

$= 6.22$ tonne

So, total weight of the block =

$WT_{blk} = W_{blk} + W_{wtr} + W_{pipe}$

$= 1083.31 + 20.37 + 5.91$

$= 1079.97$ tonne

Calculation of overturning moment about toe of anchor block

$Omy = (R \times y1) + (F_o \times h2) - (yP2 \times X1)$

$= (105.55 \times 4.37) + (144.88 \times 1.76) - ((-131.83) \times 3.5)$

$= 1178.11$ tonne.m

Resisting moment about toe of anchor block

$Rmy = (WT_{blk} \times Lw_{blk}) + (yP1 \times X1)$

$= (1079.97 \times 3.72) - ((111.04) \times 3.5)$

$= 4406.11$ tonne.m

F.O.S against overturning

F.O.S = Rmy / Omy

$= 4406.11 / 1178.11$

$= 3.74$

Check for location of the resultant

Total vertical reaction

$V_r = WT_{blk} + yP1 + yP2$

$= 1079.97 + 111.04 - 131.83$

$= 1059.81$ tonne

$x = (Rmy - Omy) / V_r$

$= (4406.11 - 1178.11) / 1059.18$

$= 3.05$ m

Eccentricity

$e = (B/2) - x$

$= (7.17/2) - 3.05$

$= 0.54$ m

Middle third of the base = B / 6

$= 7.17 / 6$

$= 1.20 \text{ m} > e$

Hence, O.K.

Check for sliding

Resultant force component in x – direction

$Rx = xP1 + xp2 + F_o$

$= 222.70$ tonne

Total vertical load of the block

$V_r = 1059.18$ tonne

Frictional resistance offered by the rock

$Sr = V_r \times \mu$

$= 1059.18 \times 0.4$

$= 423.67$ tonne

F.O.S against sliding

$F.O.S. = S_r / R_x$

$= 423.67 / 222.70$

$= 1.90 > 1.5$

Hence, O.K.

Check for base pressure

Max base pressure

$q_{max} = (V_r / (L \times B)) \times (1 + (6 \times e / B))$

$= (1059.18 / (7.34 \times 7.17)) \times (1 + (6 \times 0.54 / 1.17))$

$= 29.18$ tonne / m^2

$q_{min} = (V_r / (L \times B)) \times (1 - (6 \times e / B))$

$= (1059.18 / (7.34 \times 7.17)) \times (1 - (6 \times 0.54 / 1.17))$

$= 11.08$ tonne / m^2

qmax > S.B.C.

qmin > 0

Hence, not O.K.

From above results, S.B.C. of soil was less than q_{max}, therefore it was better to increase base dimension rather than depth of block.

- AB 2

Length of the block (L) = 6.85 m

Width of the block (B) = 7.17 m

Depth of the block (D) = 8 m

Depth of block below ground (D1) = 5.13 m

C/S area of the block (A_b) = 54.80 m^2

Length of the pipe P1 inside the block (a) = 3.86 m

Length of the pipe P2 inside the block (b) = 4.57 m

Length between cg of block from the point of rotation along resultant R (X1) = 3.41 m

Distance of pipe intersection to edge of block (X1) = 3.27 m

Distance of the pipe intersection from the base of the block (Y1) = 4.37 m

So for different dimension for the anchor block we had the following results:

Anchor Block No.	L	B	D	Weight	Over turning factor	Location of resultant	Sliding factor	q_{max}	q_{min}
AB 1	7.34	7.17	8	1079.9	3.74	0.54	1.90	**29.18**	11.08
AB 2	6.85	7.17	8	1010.6	3.36	0.88	1.81	**35.01**	5.30
AB 3	6.85	7.17	7.59	960.33	3.35	0.87	1.81	**33.03**	5.23
AB 4	6.85	7.17	7.37	933.32	3.28	0.88	1.79	**32.30**	4.86
AB 5	6.85	7.17	6.19	789.54	2.92	0.97	1.65	**28.34**	2.92
AB 6	6.85	7.17	5.73	714.53	2.72	1.03	1.56	**26.30**	1.91
AB 7	6.86	7.17	5.51	706.2	2.62	1.14	1.57	**27.21**	0.67
AB 8	6.85	8.21	5.58	814.06	3.60	0.66	1.67	**20.91**	7.26
AB 9	6.85	8.21	5.14	741.34	3.19	0.91	1.61	**20.40**	5.18
AB 10	**6.85**	**8.21**	**4.71**	**692.06**	**3.03**	**0.86**	**1.55**	**19.39**	**4.45**

Table 4.5 Results for different types of shape for horizontal type bend

As AB 10 had lesser weight and fulfilling all the conditions it was the optimum shape for these analysis of Bend 5. Results of which were as follows:

The software for Analysis, Design and Optimizing Anchor Block has been developed in visual basic 6. The basic source code of software has developed in object oriented programming (OOP) environment. In order to include the most possible interactive features, varieties of controls and functions were used.

C.G. Menu

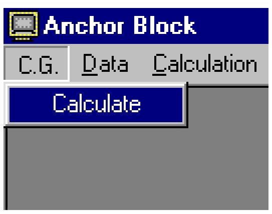


Figure 5.1 Menu bar for C.G.

Puropose

The C.G. Menu allows the user to perform calculation of center of gravity of Anchor Block.

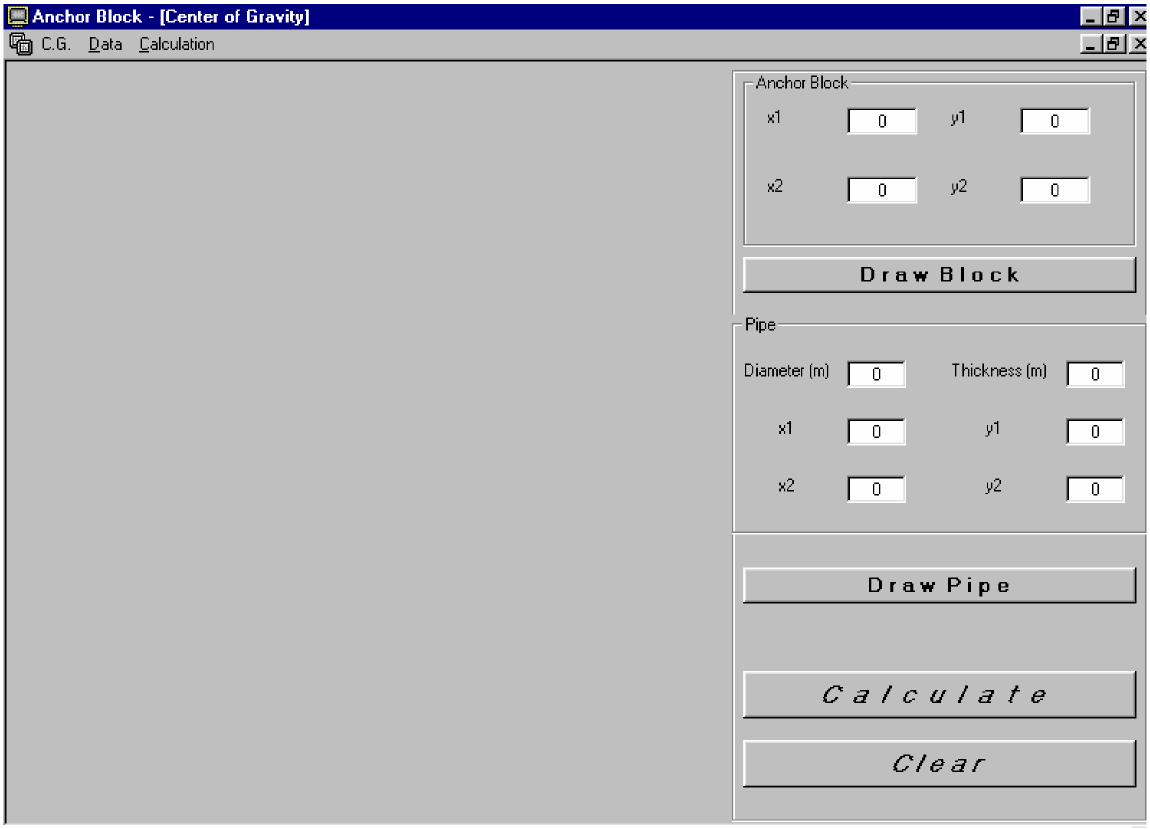


Figure 5.2 Form to find c.g. of Anchor Block

x1 = x co – ordinate of the starting point of line drawn for the Anchor Block.

y1 = y co – ordinate of the starting point of line drawn for the Anchor Block.

x2 = x co – ordinate of the ending point of line drawn for the Anchor Block.

y2 = y co – ordinate of the ending point of line drawn for the Anchor Block.

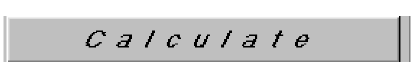
Same for pipe,

x1 = x co – ordinate of the starting point of center line drawn for the Pipe.

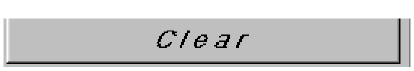
y1 = y co – ordinate of the starting point of center line drawn for the Pipe.

x2 = x co – ordinate of the ending point of center line drawn for the Pipe.

y2 = y co – ordinate of the ending point of centerline drawn for the Pipe.



This option gives you Center of Gravity of Anchor Block.



This option clear the figure drawn on form, so that user can draw another figure on form without closing it.

Data Menu:

Purpose:

Data Menu facilitate the user to input his data and also facilitate to change it during the programme.

Input ⇒ General

In General input user was enter the data as shown in Figure 5.3.

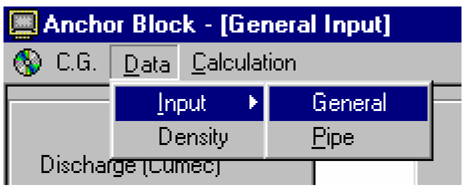


Figure 5.3 Menu bar for general data input

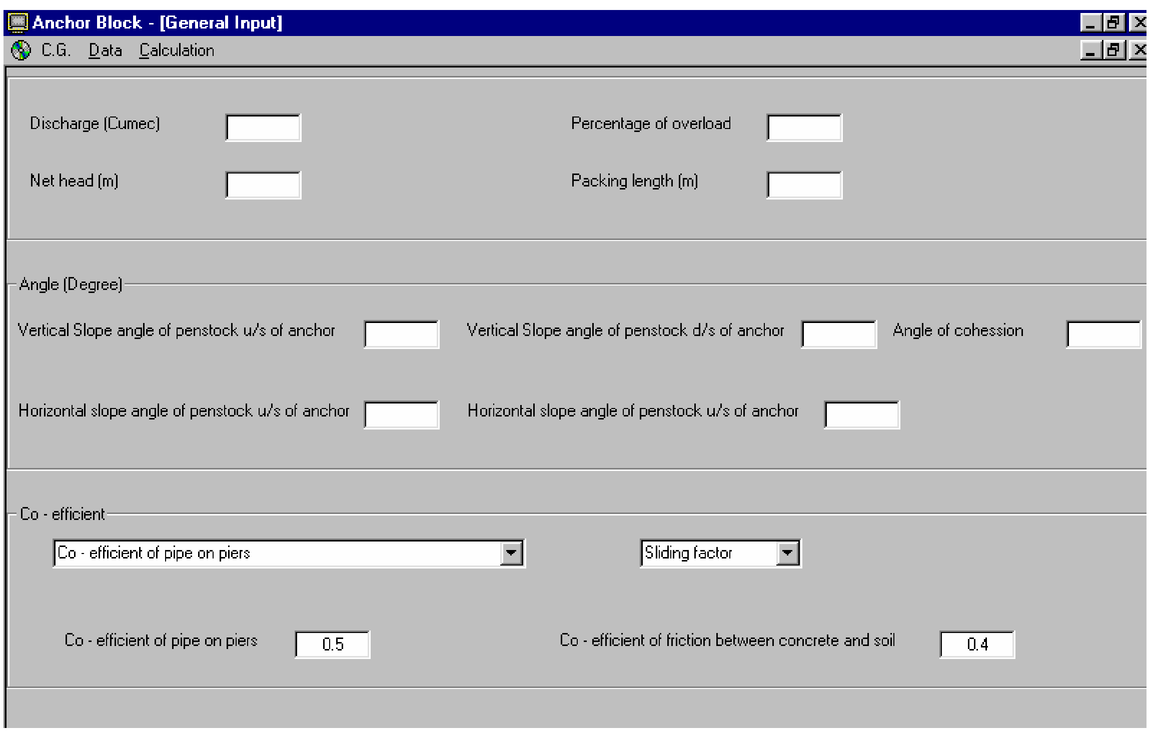


Figure 5.4 Form to input General data

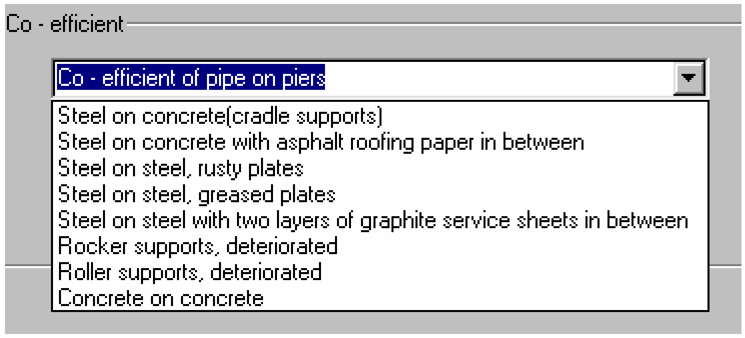


Figure 5.5 Combo box showing co – efficient of pipe on piers

User can enter co – efficient of pipe on piers from the combo box, respective value comes in text box. User can also enter another value directly in text box.

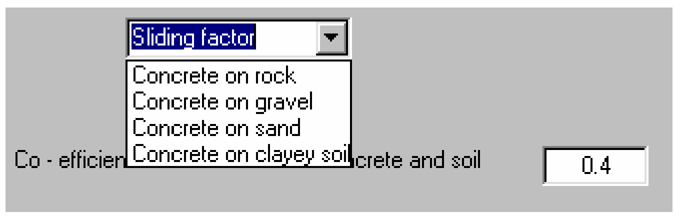


Figure 5.6 Combo box showing sliding factor

Similarly, user can enter sliding factor.

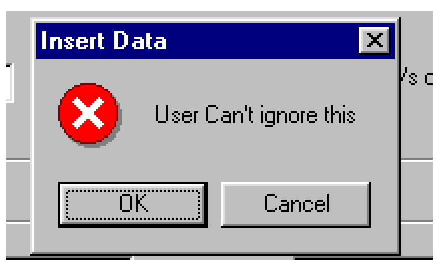


Figure 5.7 Msg box for inserting only numeric data in to text box

If user does not enter any data in text box then it will give Msg Box shown in figure and cursor goes back to that text box. So user can't leave that text box empty after once got focusing in that text box.

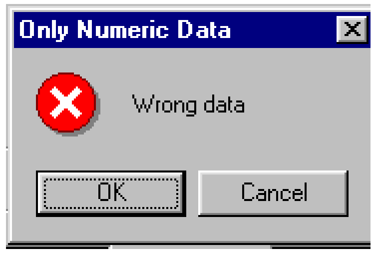


Figure 5.8 Msg Box for inserting wrong data other than numeric

If user enter any non – numeric data then also it will give Msg Box shown in Figure 5.8 and text box get empty and cursor returns to that text box. So user can not enter any non – numeric data in to text box.

Input ⇒ Pipe

Here user was enter length, diameter and thickness of pipe.
To make the user clear about length of pipe, whenever the cursor got focus on particular text box then user can see the drawing on just right of it as shown in figures below.

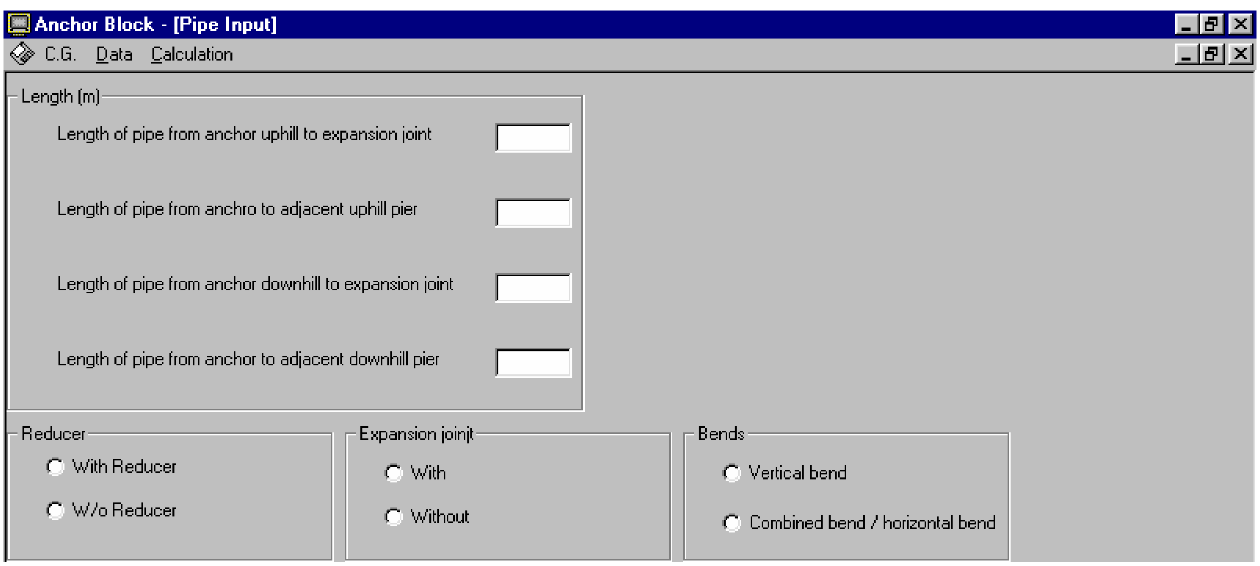


Figure 5.9 Form window for input pipe data

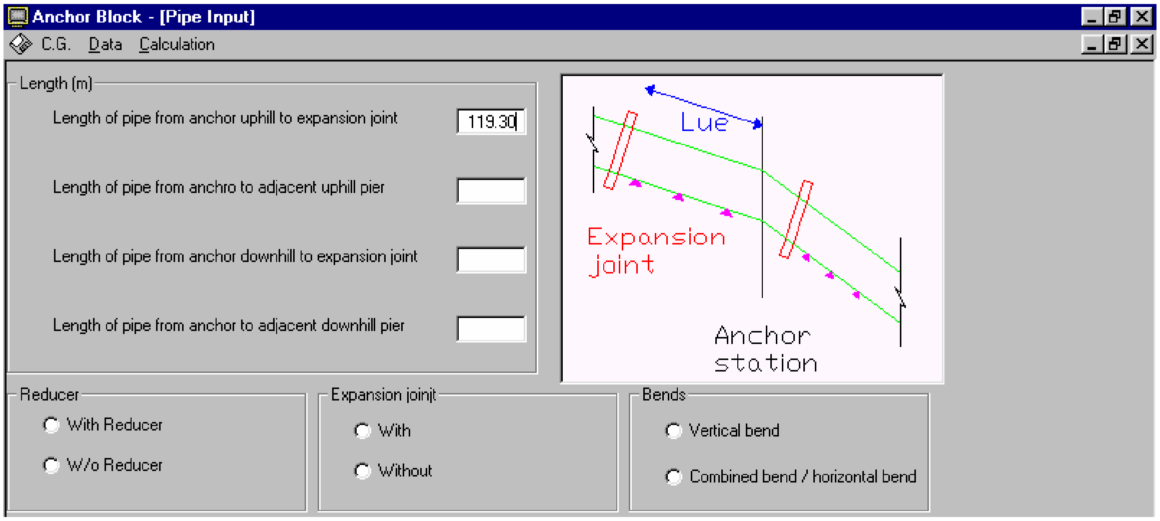


Figure 5.10 Form window showing length L_{ue}

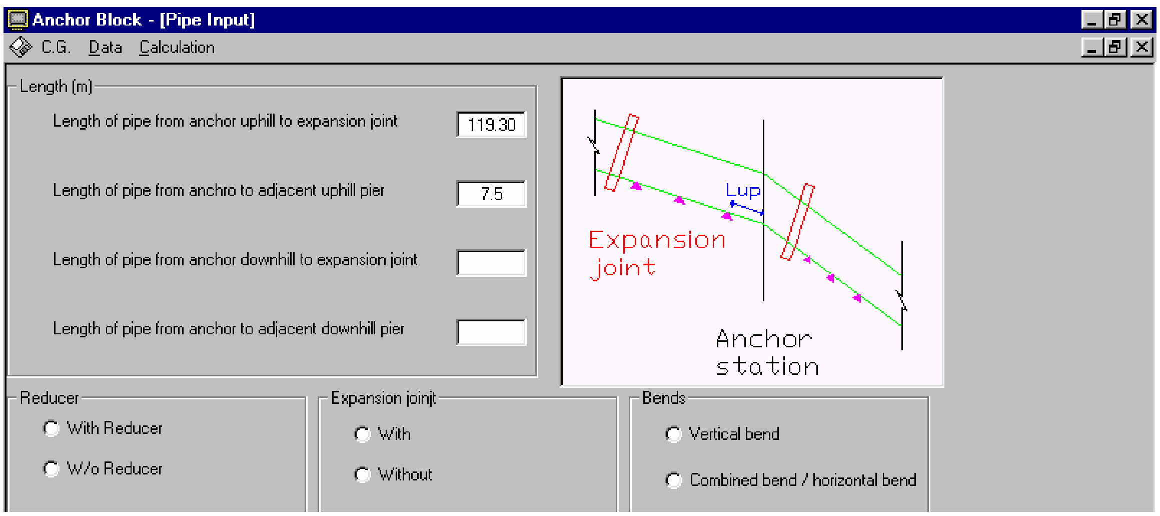


Figure 5.11 Form window showing length L_{up}

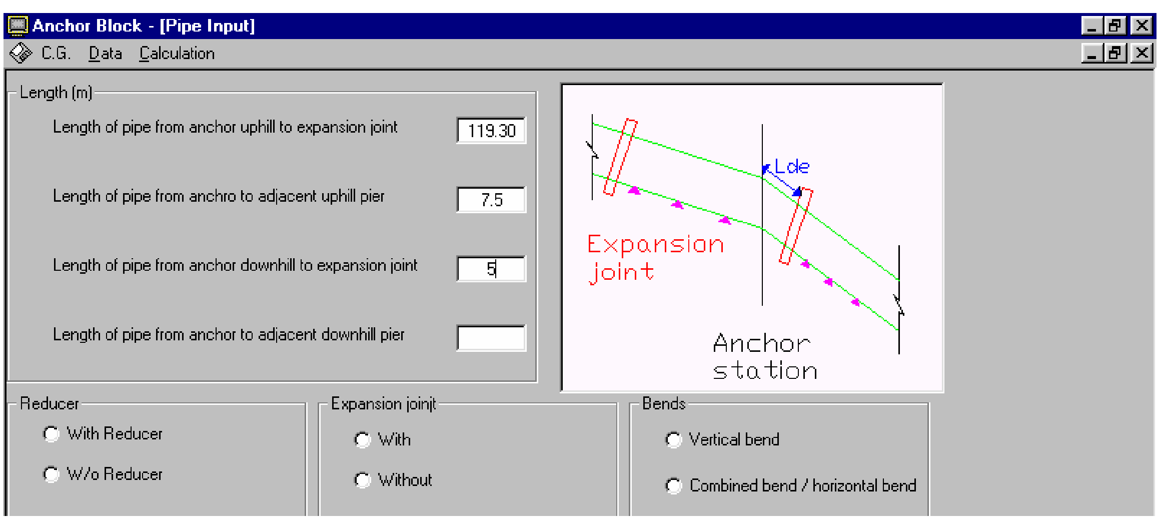


Figure 5.12 Form window showing length Lde

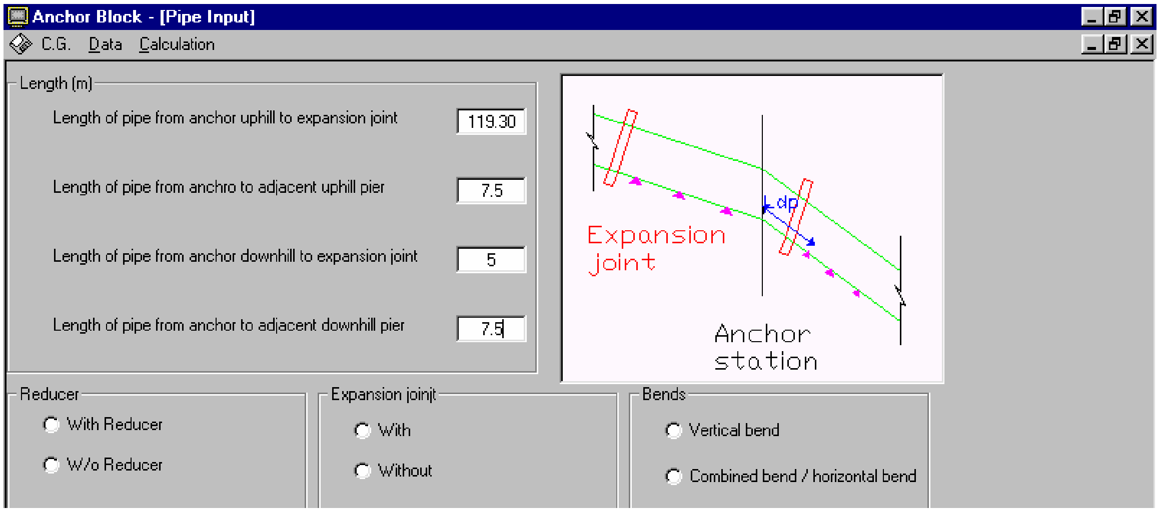


Figure 5.13 Form window showing length Ldp

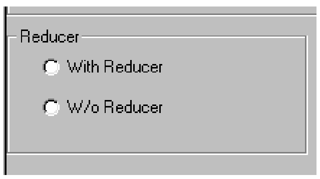


Figure 5.14 Frame giving option button for reducer

This two option button will give the user that anchor block having pipe with Reducer or without Reducer. This will also help in reducing the number of input, if pipe is providing without Reducer as shown in Figure 5.15

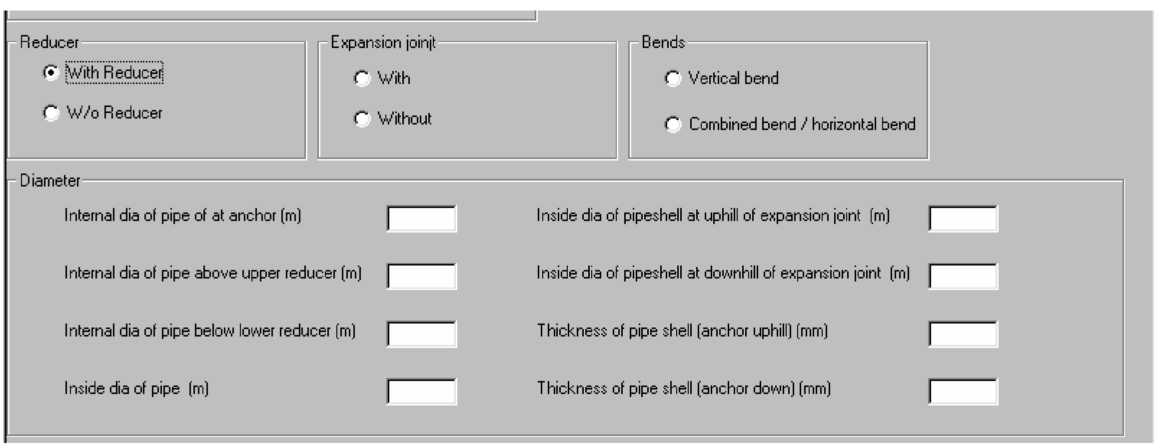


Figure 5.15 Form showing input for pipe when anchor block provided with reducer

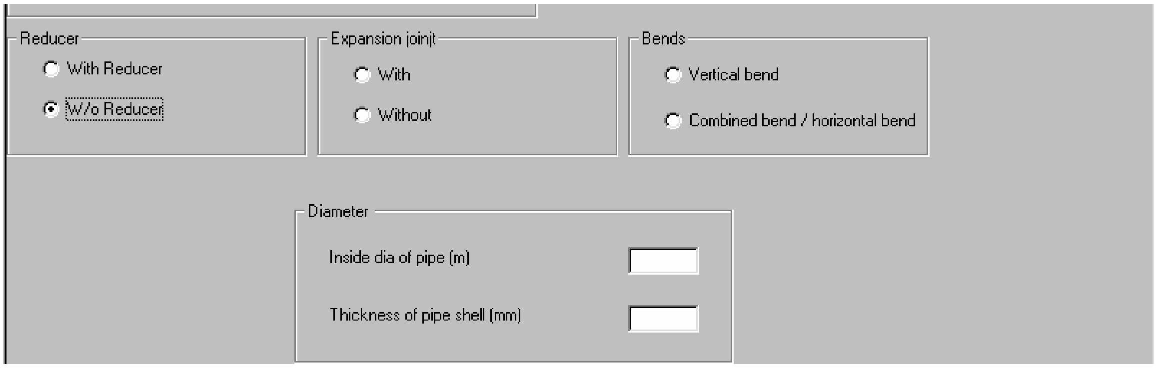


Figure 5.16 Form showing input for pipe when anchor block provided without reducer

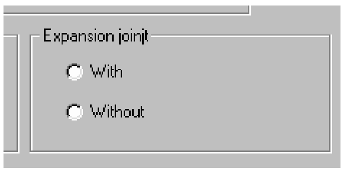


Figure 5.17 Frame giving option button for expansion joint

This two option button will give that pipe is providing with or without Expansion Joint.

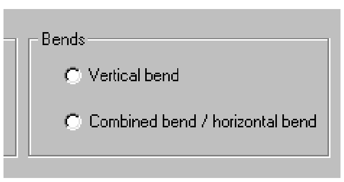


Figure 5.18 Frame giving option button for bend type

This two option button will gives that the pipe is simply vertically bend or it will providing combined or horizontal bend.

Density

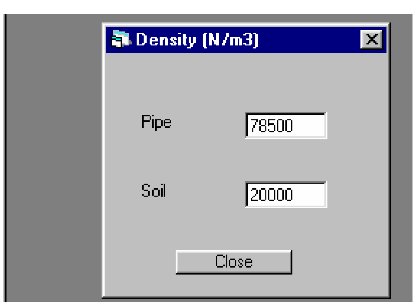


Figure 5.19 Dialog box for input of density of material

This option will give small dialog box on screen in which user can enter density of pipe and soil. By default pipe density set to 78500 N / m^3 and soil density set to 20000N / m^3, but user can also change this values.

Calculation Menu:

Calculation ⇒ Analysis

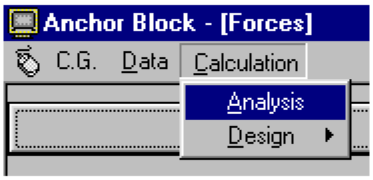


Figure 5.20 Menu bar for analysis of Anchor Block

Purpose:

This option will give the forces and it’s direction and design and detailing of the Anchor Block.

By clicking on “Analysis” user can have form as show in Figure 5.21.

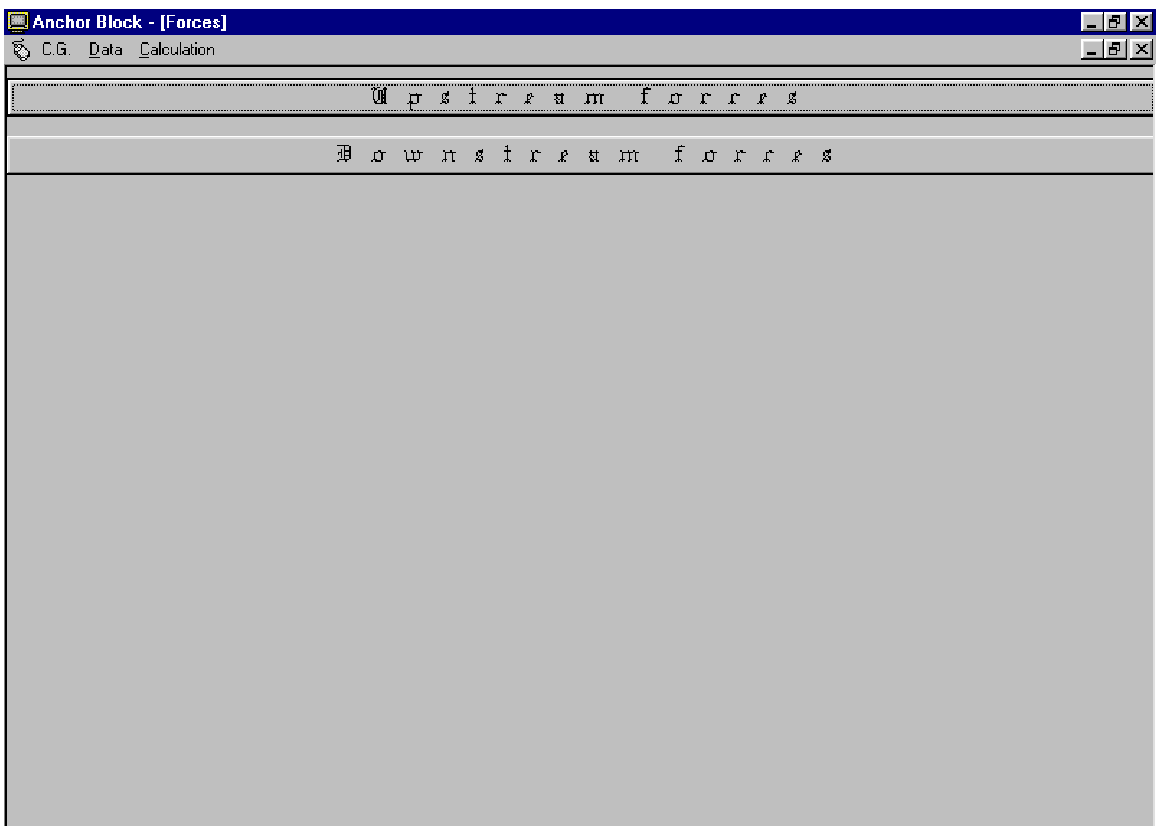


Figure 5.21 Form that giving u/s and d/s forces on Anchor Block

By just clicking on "`Upstream forces`" user gets the forces on upstream side of Anchor Block as show in Figure 5.22.

By just clicking on "`Downstream forces`" user gets the forces on downstream side of Anchor Block as show in Figure 5.23. User can have also the direction of forces on upstream and downstream side.

After getting forces on upstream and downstream side user having Governing case after clicking the "`Downstream forces`" as shown in Figure 5.23.

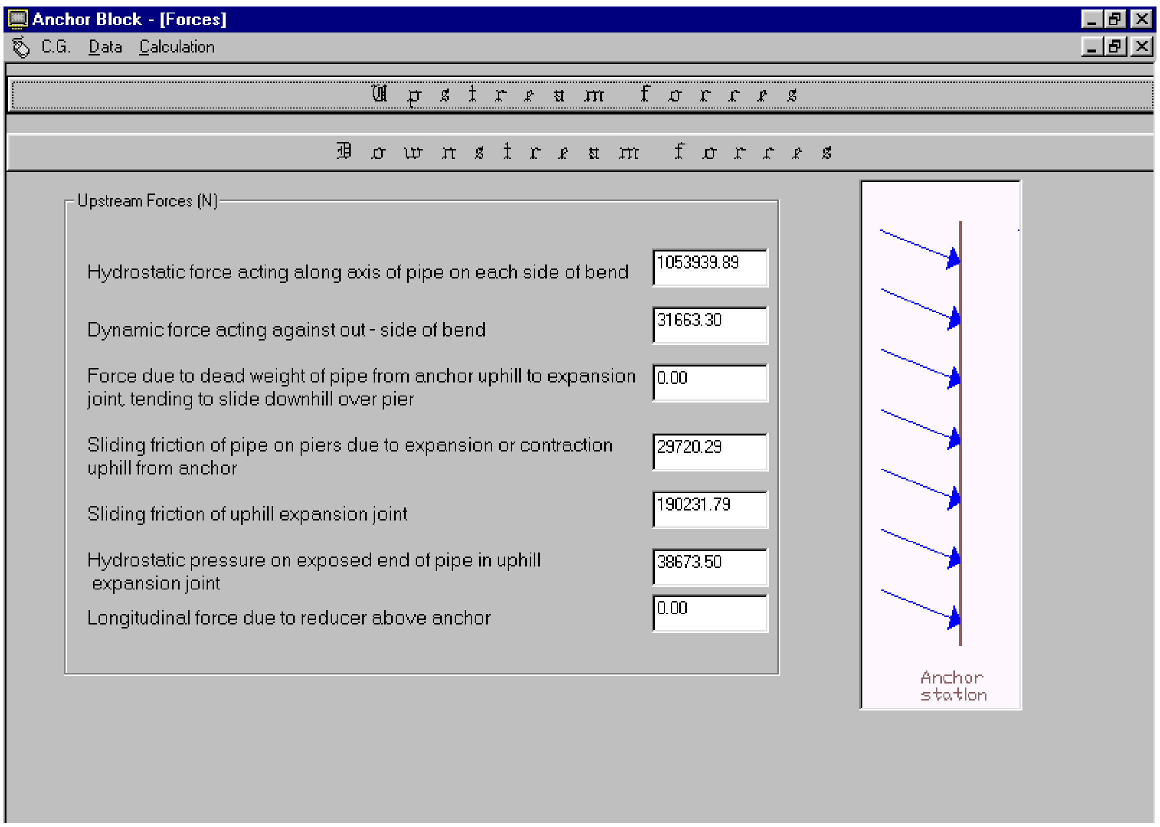


Figure 5.22 u/s forces on anchor block with direction

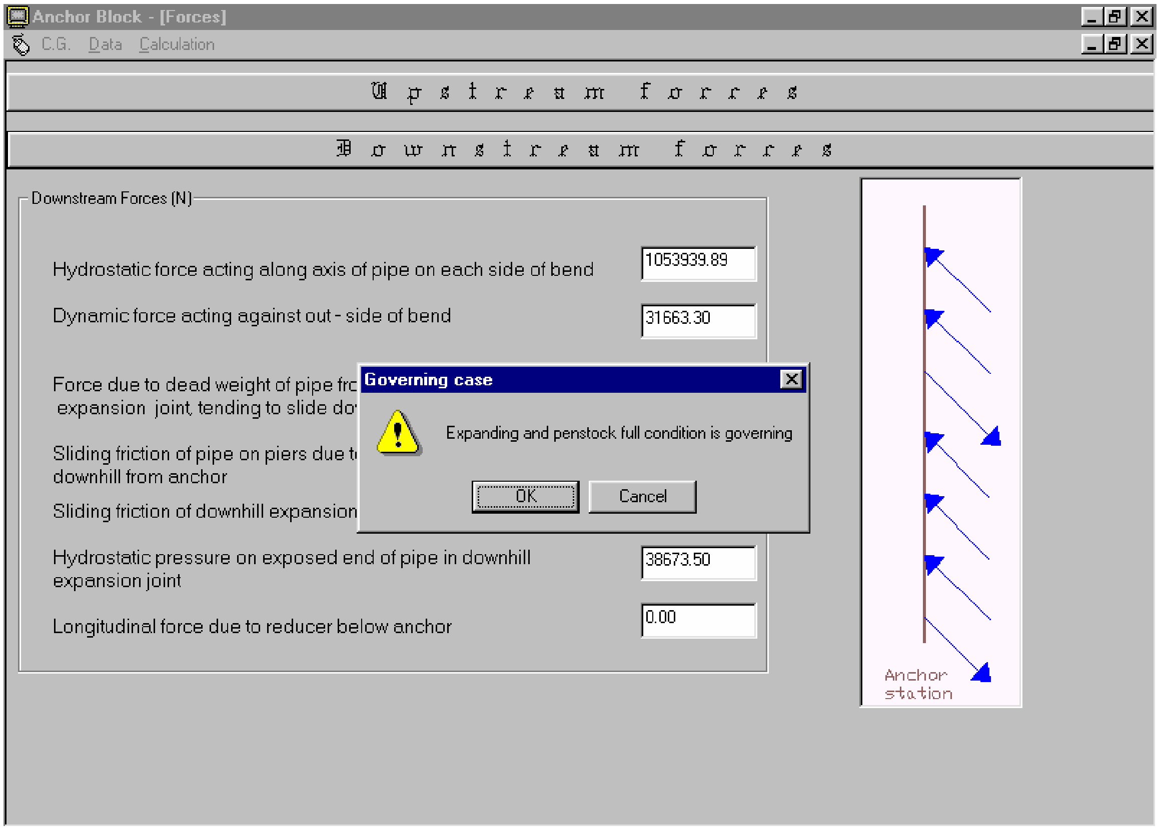


Figure 5.23 d/s forces on anchor block with direction

whenever there is the Penstock system without Expansion joint the user just have to click in button of without expansion joint. So we can have the numbers of forces and their direction as shown in Figure 5.24 and Figure 5.25 for "`Upstream forces`" and "`Downstream forces`"

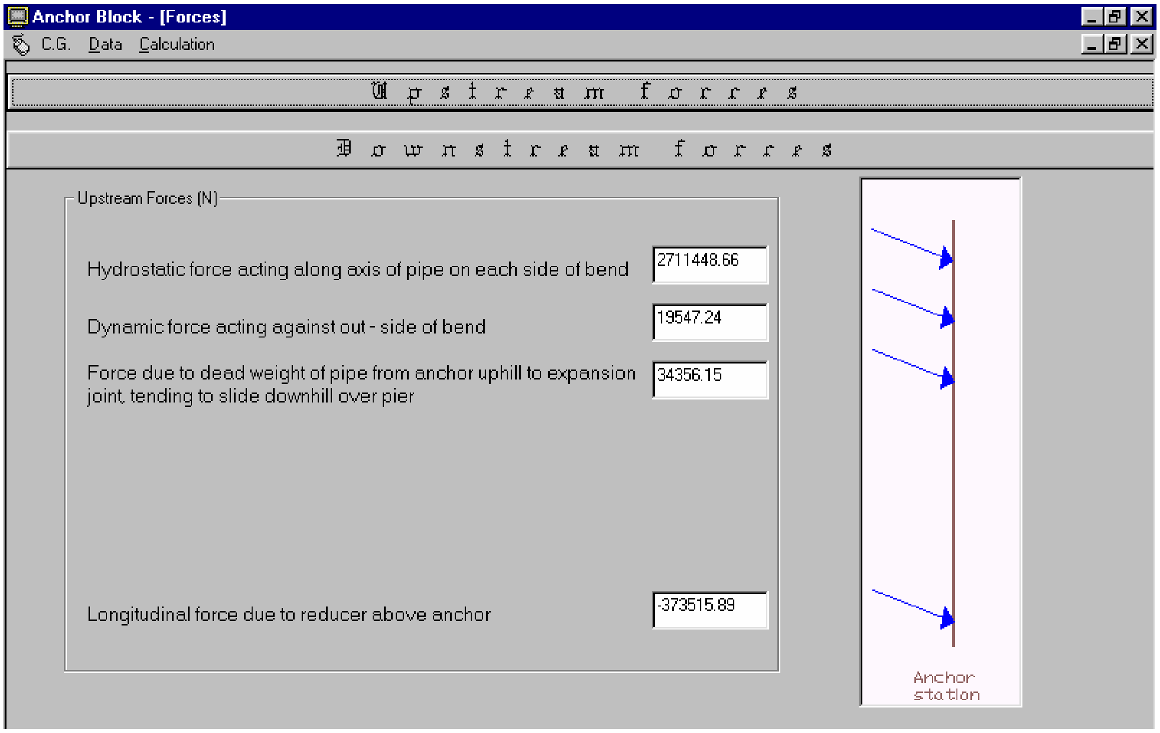


Figure 5.24 u/s forces with reducer without expansion joint with direction

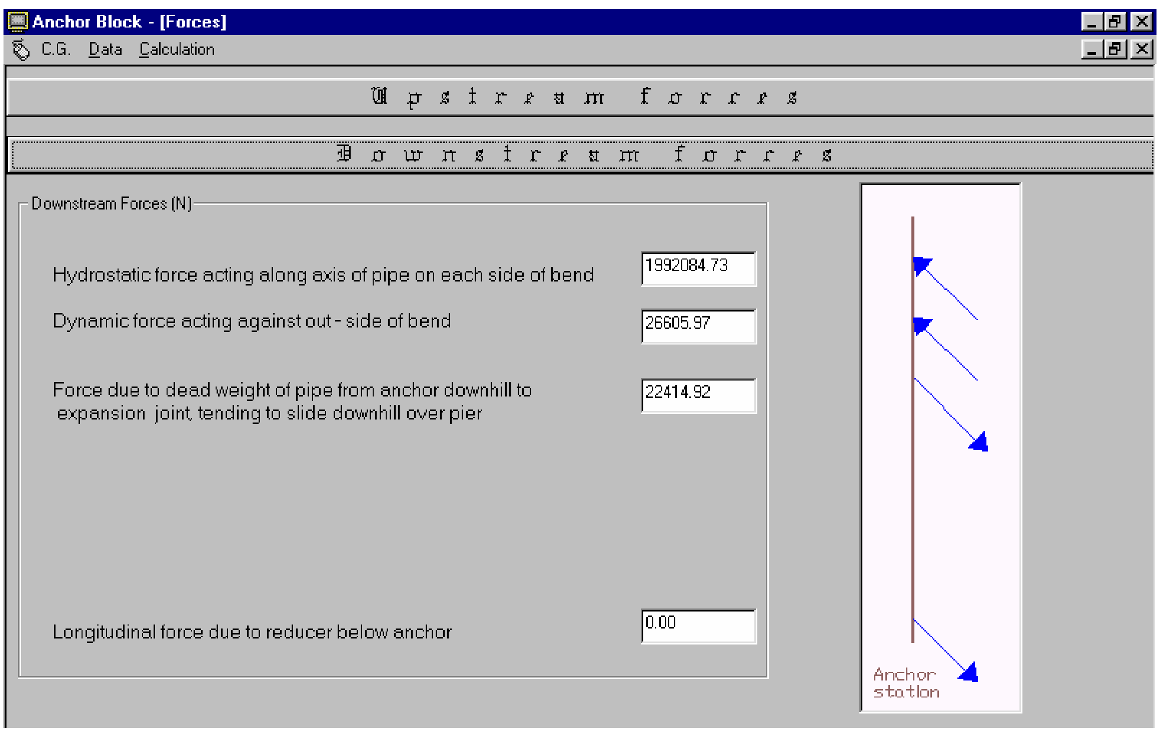


Figure 5.25 d/s forces with reducer without expansion joint with direction

Whenever there is no Reducer in Penstock system then user have to just click over W/o Reducer and user have some reduction in input data as shown in Figure 5.26 . So we can have the numbers of forces and their direction as shown in Figure 5.27 and Figure 5.28+99 for “Upstream forces” and “Downstream forces”

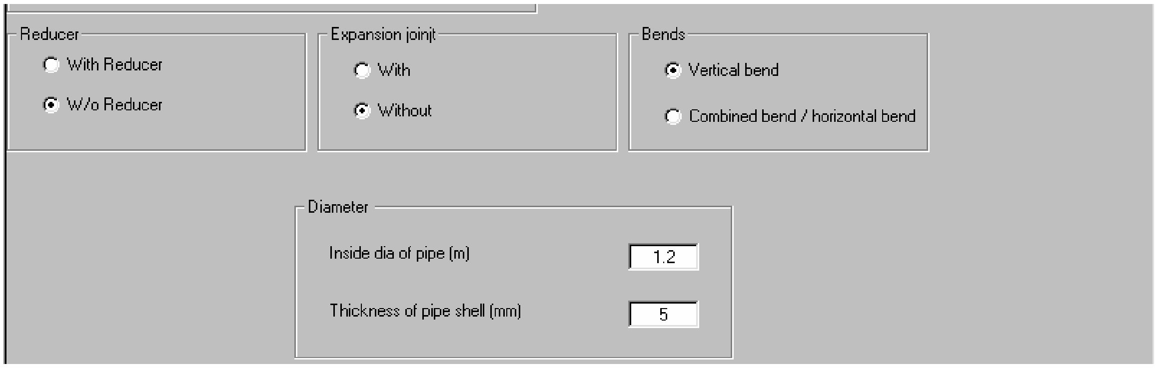


Figure 5.26 Frame showing input when anchor block was w/o reducer

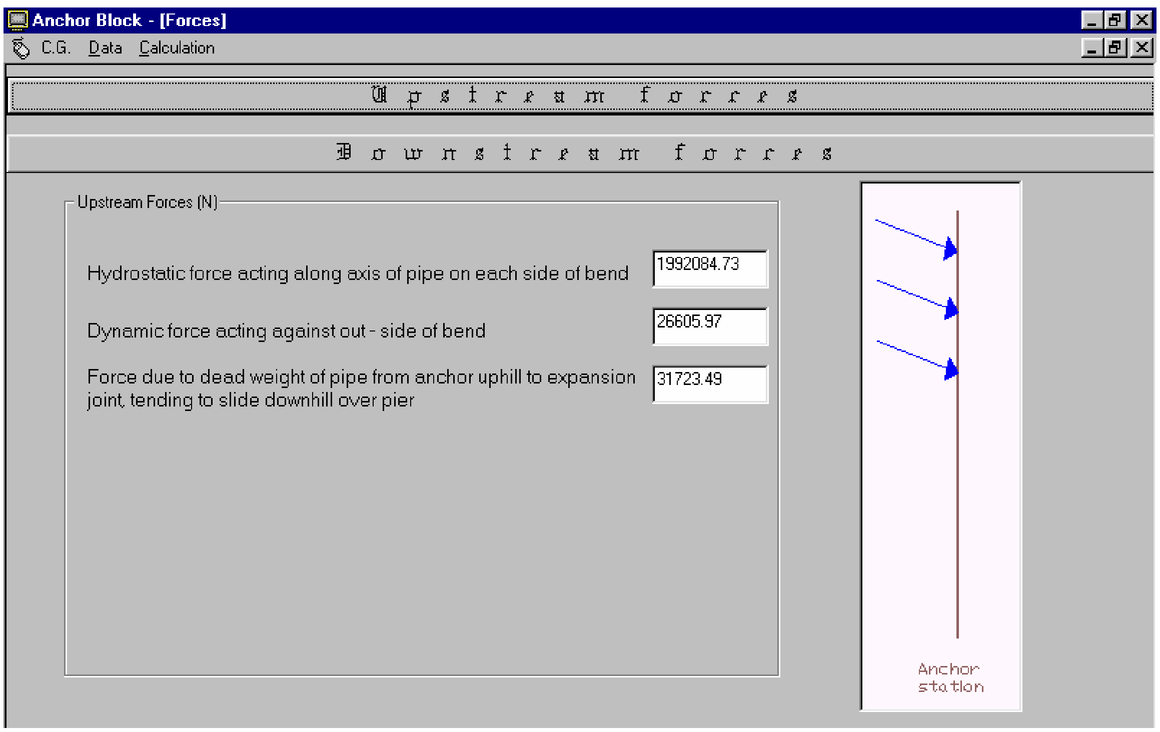


Figure 5.27 u/s forces w/o reducer w/o expansion joint with direction

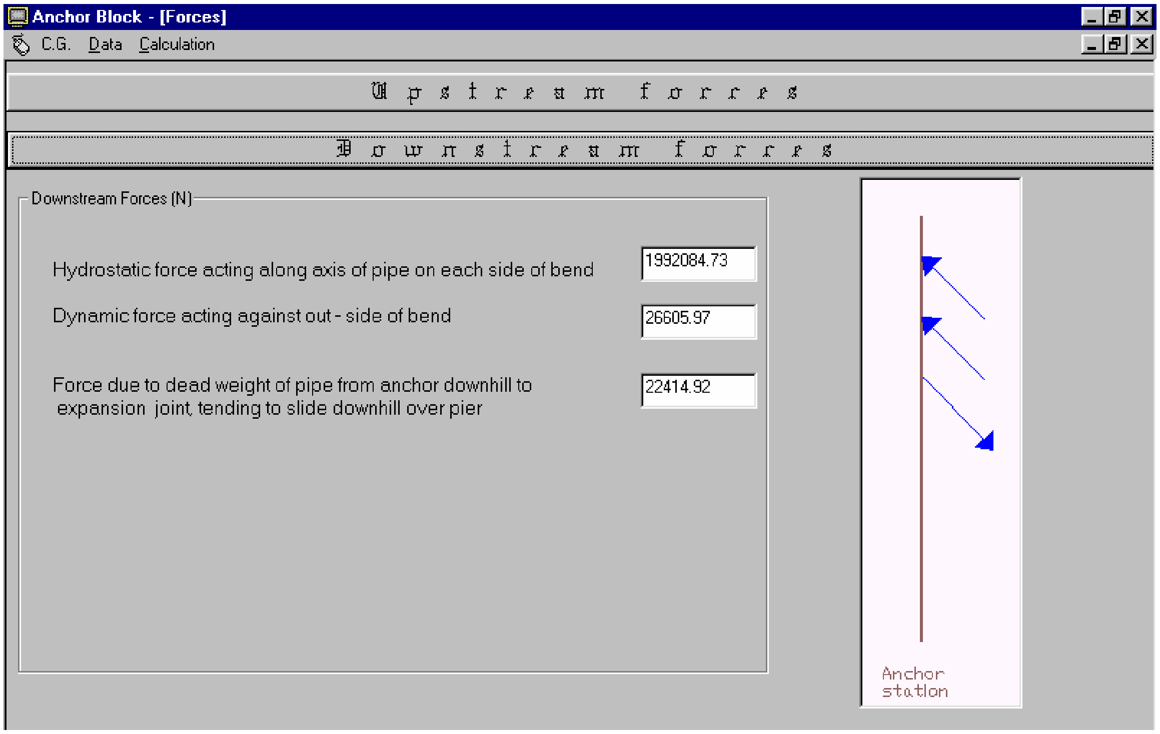


Figure 5.28 d/s forces w/o reducer w/o expansion joint with direction

Design ⇒ Checks

Puropose:

This option will give the user to have input the dimension of the Anchor Block and give all the four checks results and weight of the Anchor Block, so that user can have the optimum design of Anchor Block.

To make user known with the dimension of Anchor Block, length of pipe inside the Block, distance of pipe intersection to edge of block and to base of block, distance of the centroid of the Anchor Block from the edge of the block

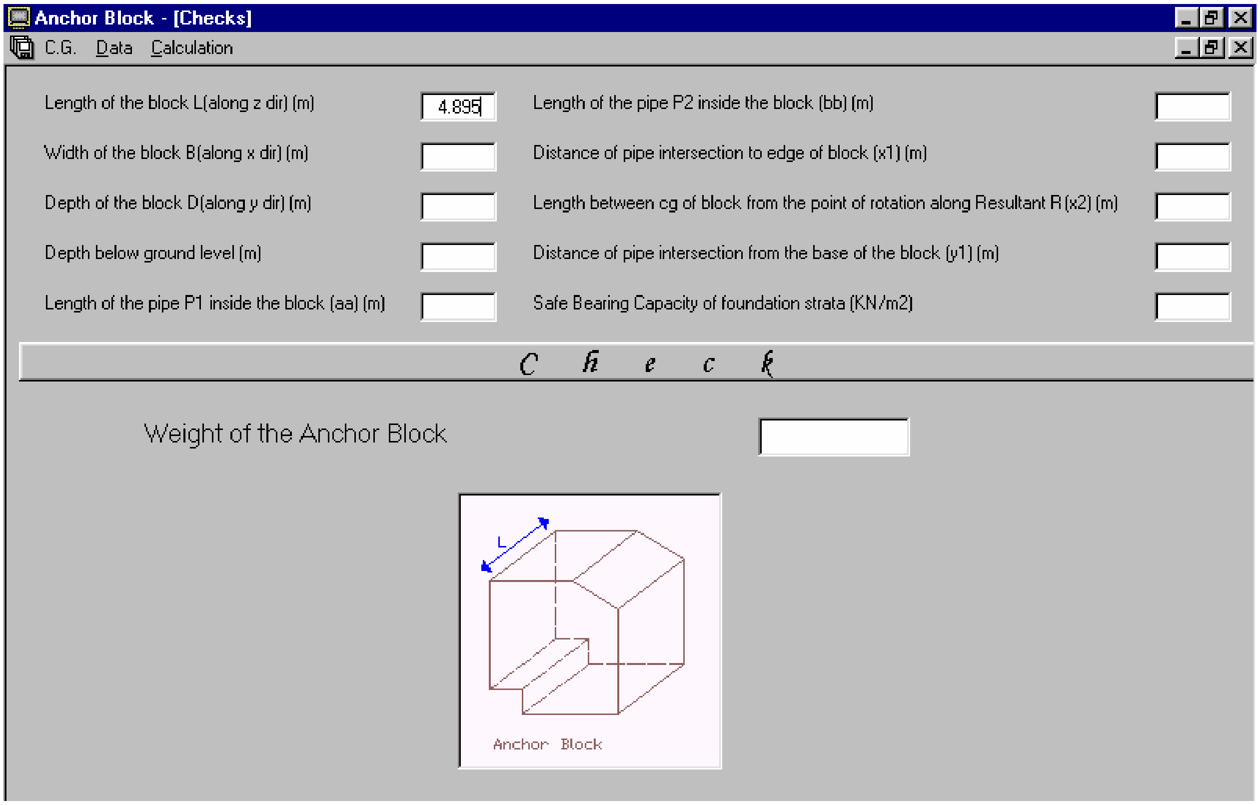


Figure 5.29 Form window showing length of Anchor Block

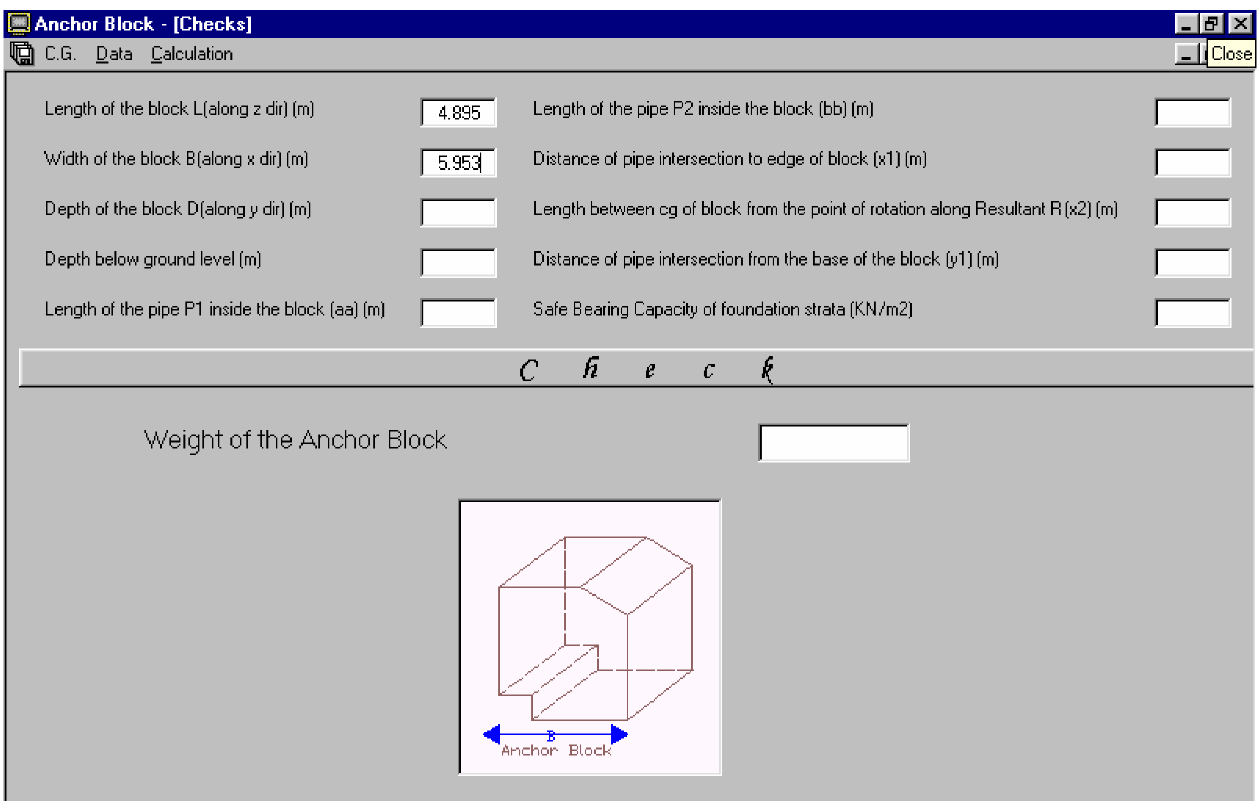


Figure 5.30 Form window showing width of Anchor Block

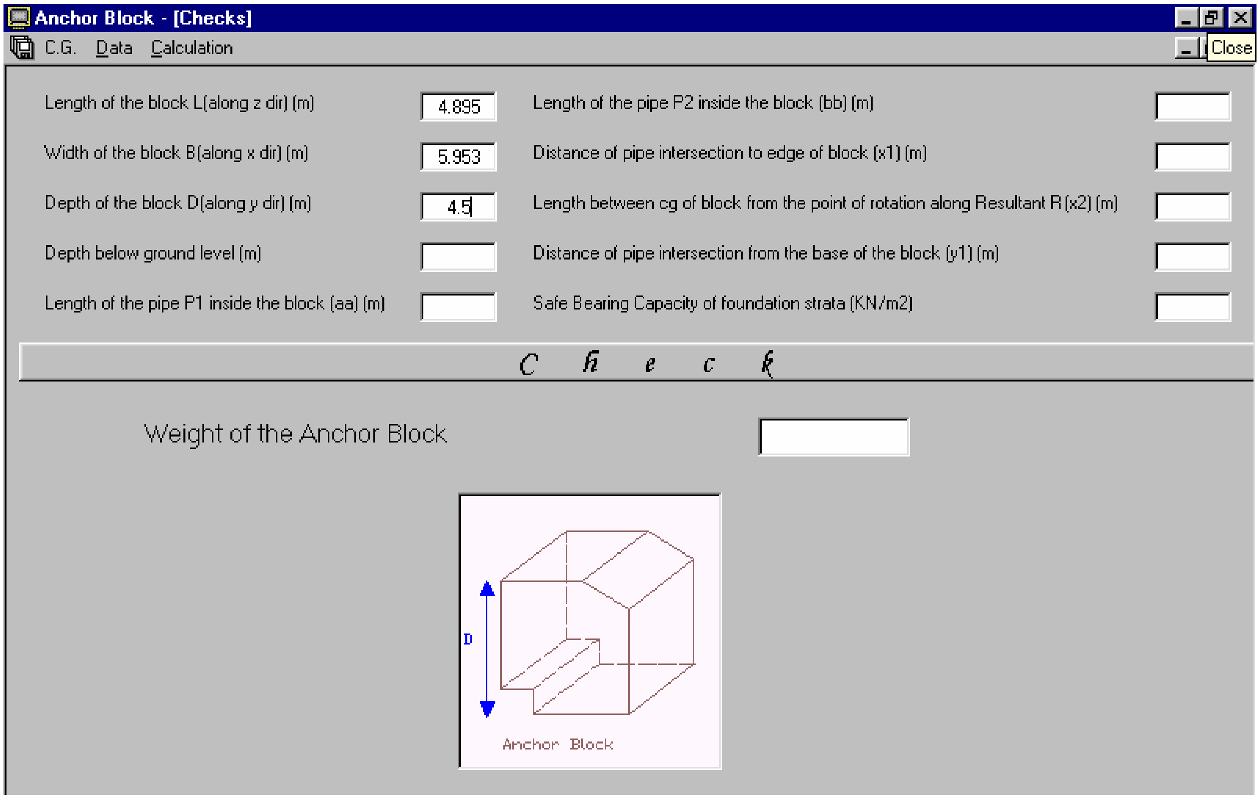


Figure 5.31 Form window showing depth of Anchor Block

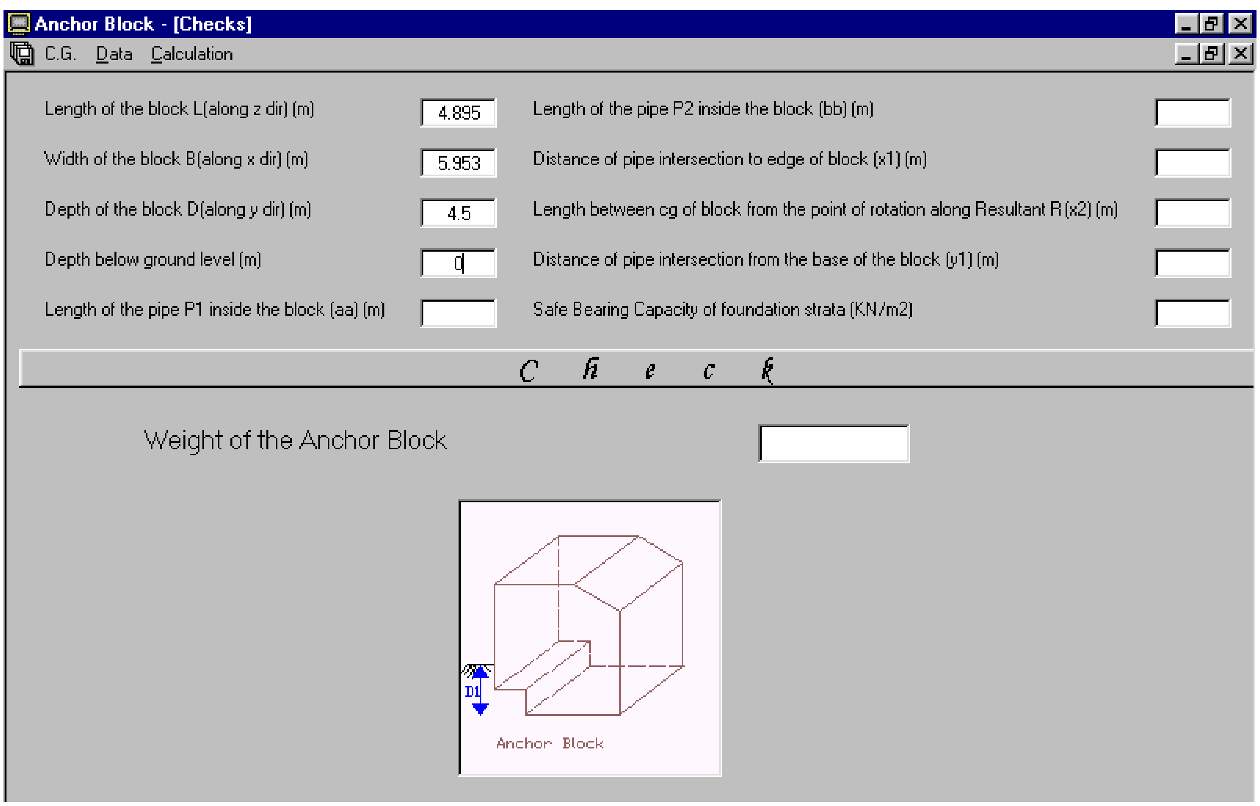


Figure 5.32 Form window showing depth of Anchor Block below ground level

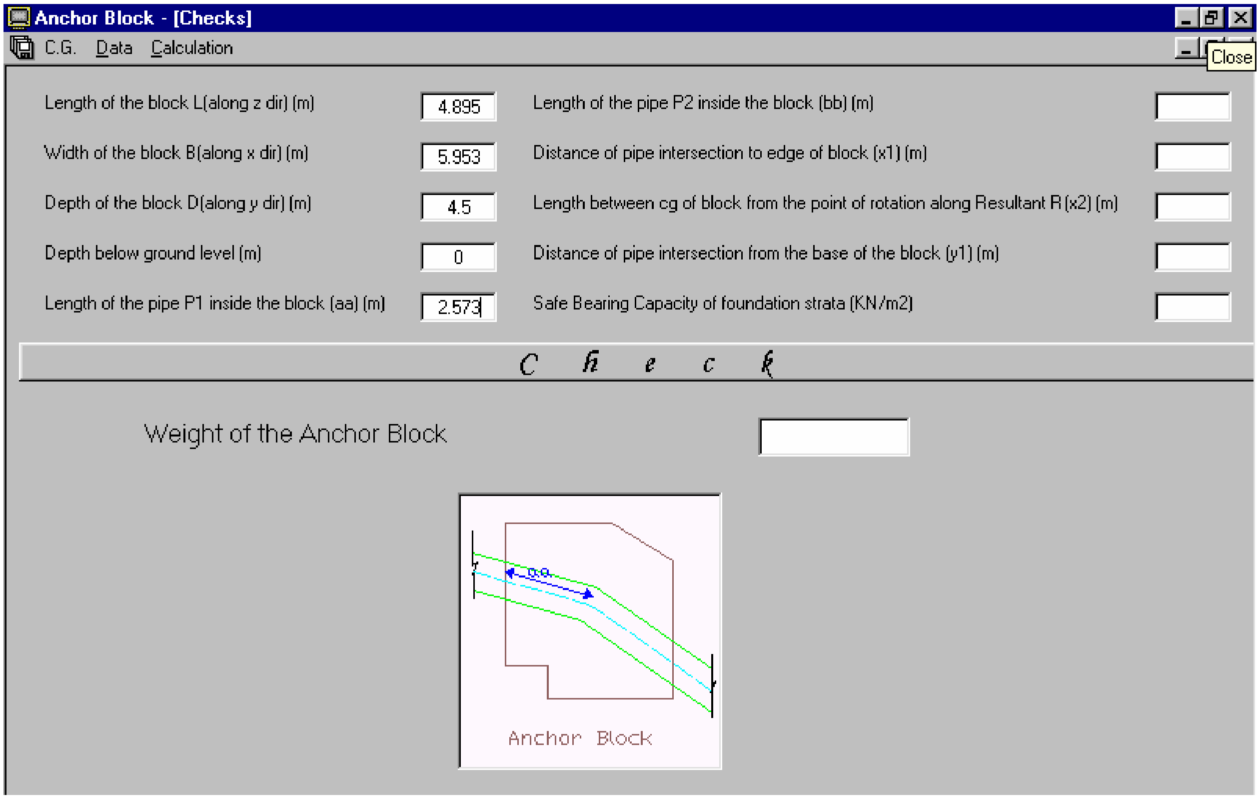


Figure 5.33 Form window showing length of u/s pipe in Anchor Block

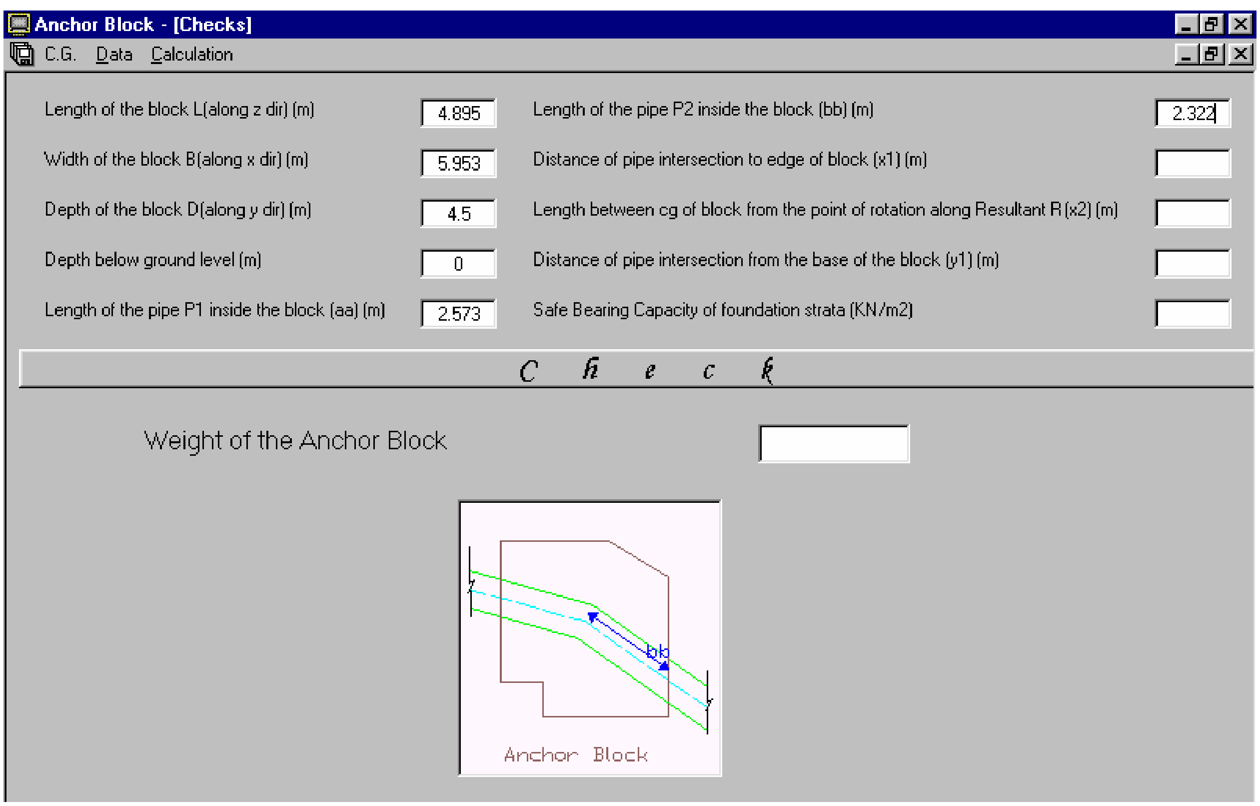


Figure 5.34 Form window showing length of d/s pipe in Anchor Block

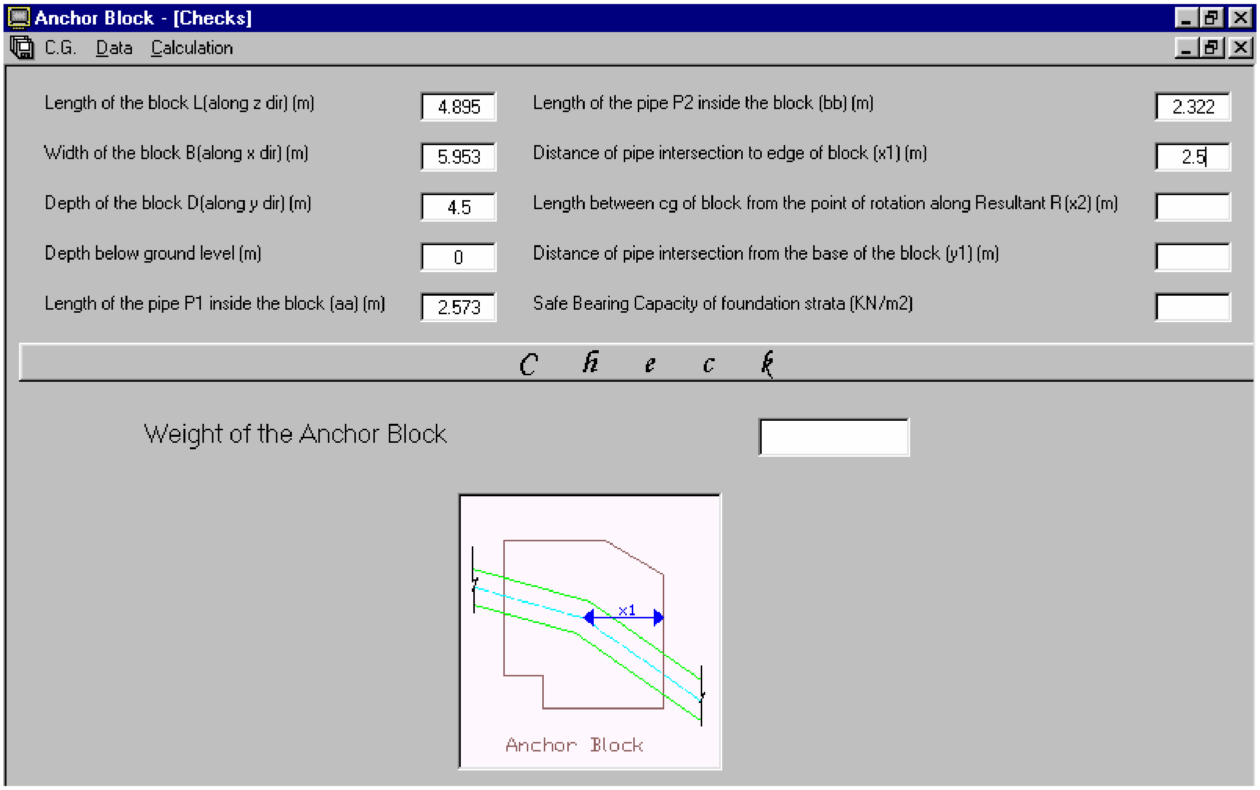


Figure 5.35 Form window showing distance x1

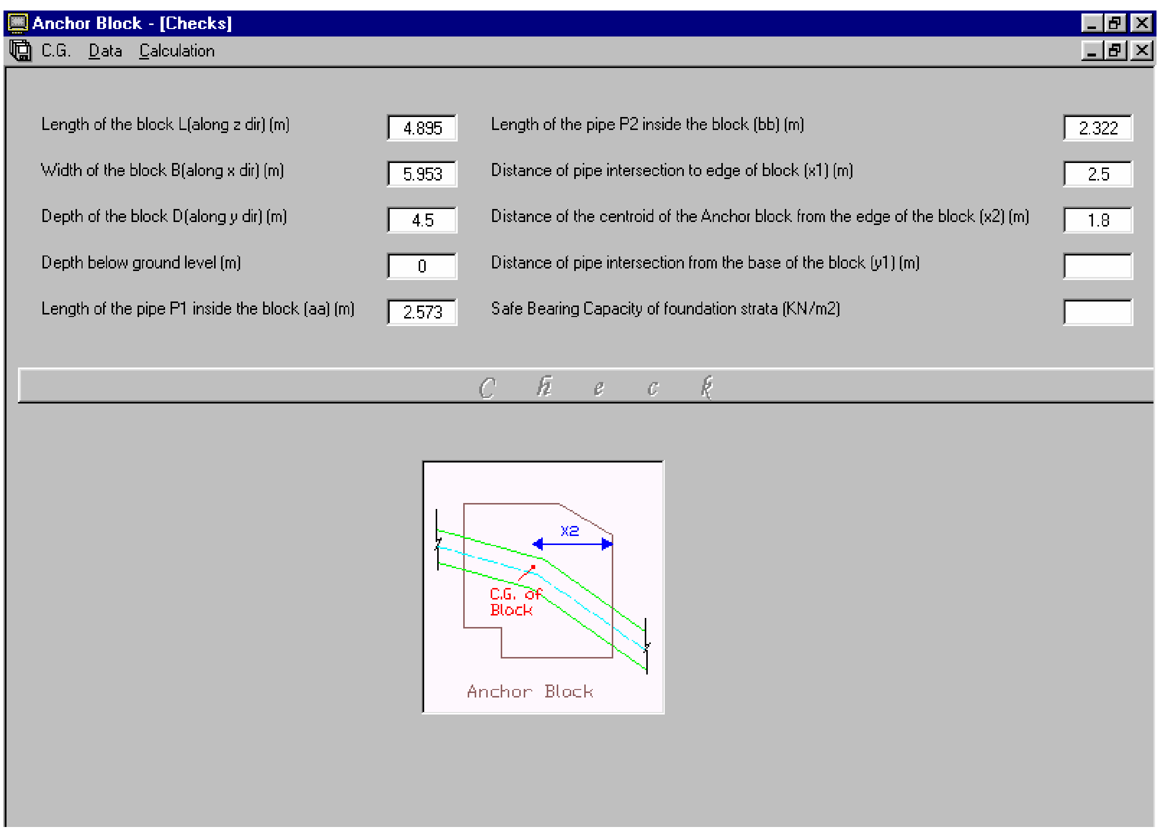


Figure 5.36 Form window showing distance x2

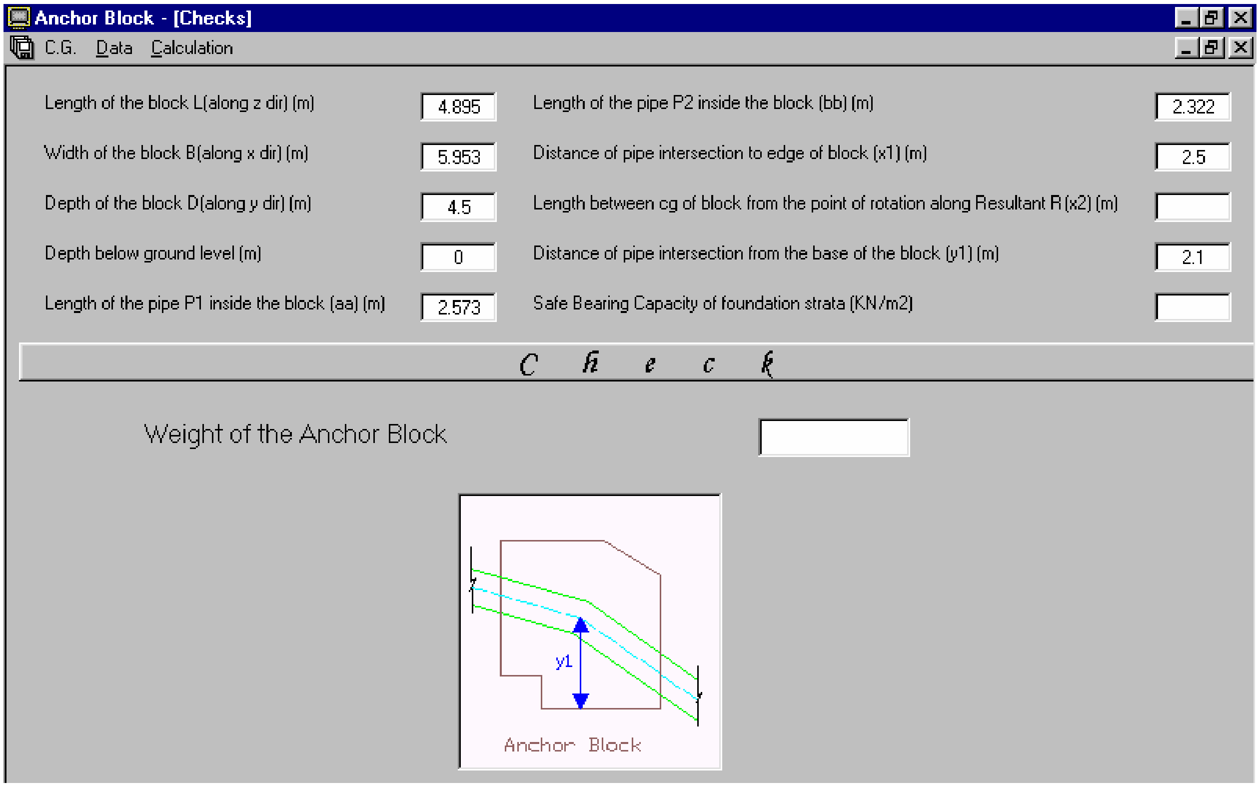


Figure 5.37 Form window showing distance y1

whenever the users input data for Anchor Block is in safer side then it in text box Results are in Green color and if they are not on safer side then Results are in Red color.

User can have also see the weight of the Anchor Block in tonne so that user can have the idea when the Anchor Block is having optimum size.

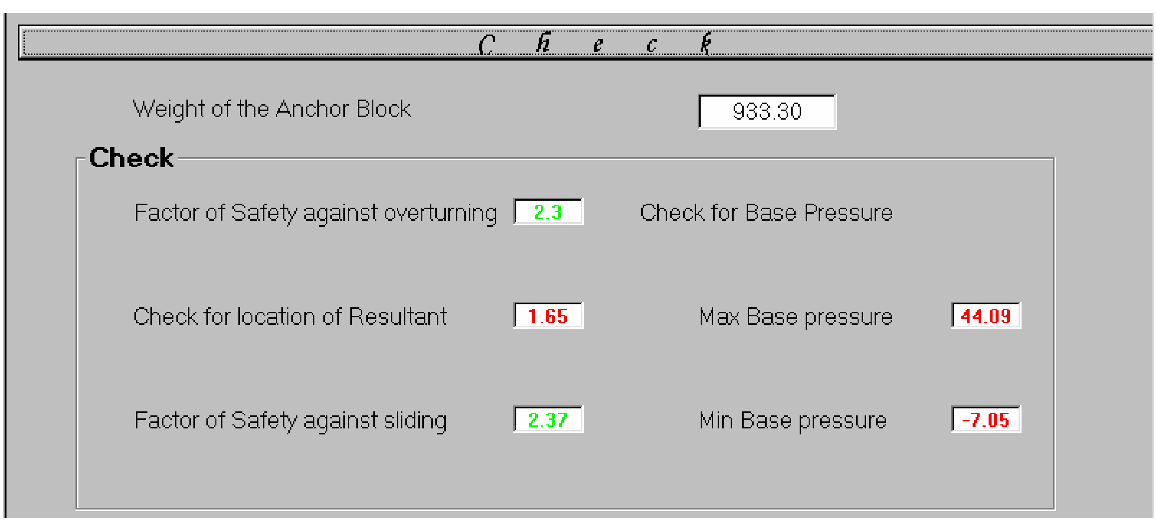


Figure 5.38 Frame showing checks for Anchor Block

Design ⇒ Detail

Purpose:

This option will give the Detail drawing of the Reinforcement for the Anchor Block. User have just enter the diameter of nominal Reinforcement and diameter of U/O alternate bars and click on "***calculate***" button, so user can have the spacing of bars as shown in figure.

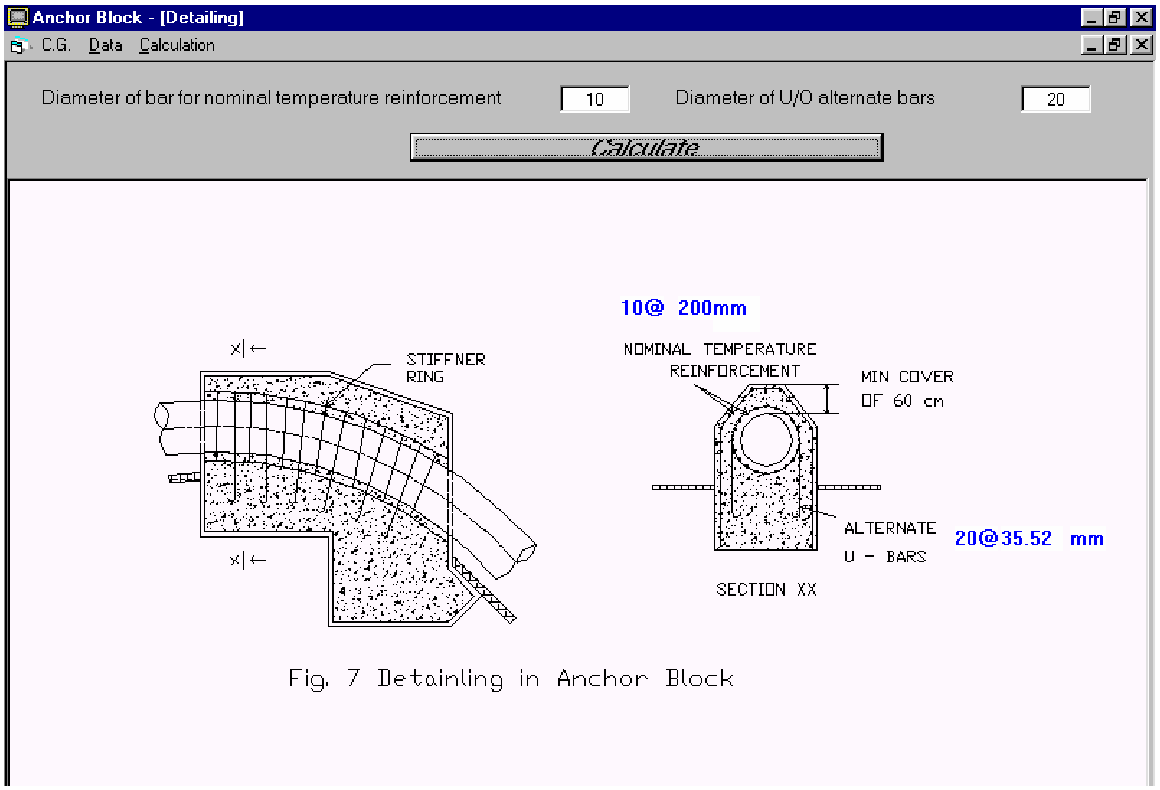


Figure 5.39 Form window showing detailing of Anchor Block

Result obtained from an analysis of Anchor Block for all different types of bends are optimized, listed below.

Table 6.1 Optimized size for different types of bends

Bend 1	2.8	2.5	2.3	46.52	2.10	0.22	1.90	15.42	4.32
Bend 2	2.8	5	2.53	92.32	1.95	0.38	2.13	19.86	7.39
Bend 3	5.5	8	5.17	565.51	2.49	0.45	1.52	16.48	8.23
Bend 4	5.28	4.51	4.32	265.69	3.41	0.38	1.51	16.72	5.59
Bend 5	6.85	8.21	4.71	692.06	3.03	0.86	1.55	19.39	4.45

- It has been observed from the results that, for the same input for concave and convex type bends, weight of block of convex type bend was 6 times more than that of concave type bend. The large difference was only because of difference of angle between pipes.

All the checks were mainly depends upon weight of Anchor Block,

- Sliding factor is more dependent on weight of Anchor Block.

- Location of resultant mainly depends upon width of block, which was along the direction of resultant.

- It has observed that, no tension was produce at any part of the Anchor Block, therefore steel provided is of minimum percentage.

- Bend 1 was the simple bend with minimum head, therefore lesser possibility of exceeding of any checks and it required lesser volume of concrete compare to all blocks in penstock system.

- Bend 2 has less possibility to fail due to sliding, as uplift load due to d/s pipe was less as bend of pipe was concave.

- Bend 3 has more possibility to fail due to sliding, as uplift load due to d/s pipe was more as bend of pipe was convex.

- Bend 4 has also possibility to fail due to sliding, as pipe having simple horizontal bend therefore not having any vertical load from the pipe.

- Bend 5 required larger volume of concrete due to high head of water, and having both vertical as well as horizontal bend.

Future Scope of Work

Looking to the work done in present thesis following work can be taken as future scope of work related to this topic.

- Optimizing the three(branch) pipe system.
- Analysis and optimum design of Anchor Block where hard rock is not available.

Reference

1. M. M. Dandekar and K. N. Sharma, "Water Power Engineering".
2. P. S. Nigam, "Handbook of Hydro Electric Engineering".
3. "Thrust Restraint Design for Ductile Iron Pipe"
4. "Thrust Block Instructions"
5. "Penstock" U. S. Army Corps of Engineers.
6. "Thrust blocking" U. S. Army Corps of Engineers.
7. "Mastering VB 6" Evangelos Petroutsos.
8. "VB 6 Fundamentals" Peter Write.