SUPPORTING STRUCTURES FOR OVERHEAD CRANES IN UNDERGROUND POWERHOUSE

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ABSTRACT

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Bridge cranes are used for handling loads over an entire floor area, of one or more bays, between two lines of columns.

The supporting structures are designed for the static wheel loads plus impact and breaking forces induced by the bridge cranes at full lifting capacity. In some cases, earthquake forces and thermal stresses are also taken into consideration in the final design of such structures.

The structural supporting system of bridge cranes generally includes: beams, columns, bracings and tie beams. These structural elements are either of structural steel or of reinforced concrete.

Crane beams provide continuous support for the crane rails on which the crane wheels are moving. In addition to these moving loads, the crane beams are subjected to lateral forces induced by the crane wheels when stopping the main trolley which carries the lifted loads.

The columns supporting the beams transfer the forces to the substructure or to the ground. The spacing between the columns governs the size of the beams and limits the loads to be carried by the columns.

Bracings are required to resist longitudinal forces and usually are located between each expansion joint of the crane beams on both lines of columns.

Tie beams are used to provide lateral support to individual columns.

Cranes of large lifting capacity are generally required in hydroelectric powerhouses.

The surface powerhouses are always built with crane beams and columns to support the heavy overhead cranes. The underground powerhouses, if excavated in a good quality of rock, present also, the alternatives of supporting the cranes, either over rock shoulders excavated on the top of the rock walls, or over steel, or concrete brackets post-tensioned to the rock walls of the powerhouse. Preliminary analysis and design are required for the various types of supports, in order to choose the one which is efficient and more economical for the whole project.

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INTRODUCTION

The selection and optimization of various types of structural supports for bridge cranes in a hydroelectric underground powerhouse and guidelines for the preliminary analysis of continuous crane beams and stepped columns, represent the object of this report.

A preliminary analysis and design are sufficient to select the size of the members for the different types of supporting structures, in order to evaluate and determine their comparative cost estimate. A final analysis and design of all the components of the most economically chosen supporting system needs still to be done, but this is beyond the scope of this report.

The choice of an underground powerhouse is dictated by the frequent use by them of heavy cranes with large lifting capacities.

An underground powerhouse, if excavated in a rock of good structural quality, presents the alternative of various types of supporting structures for overhead cranes.

Overhead cranes capable of handling heavy loads are also found in pulp and paper mill buildings and in transformer's factories, but the types of crane supporting structures in these cases, are limited to beams and columns.

The types of crane supports are also selected in the function of the crane-lifting capacity and the clearance requirements.

A type of supporting structure and the main components of a turbo-generator unit in a hydroelectric underground powerhouse are shown in Figure 1.1.

The heaviest single parts of the unit to be lifted by the overhead crane are: the rotor, the runner and the main shaft. Very often, in order to handle these parts, it is required to use two cranes working in tandem, as shown in Figure 1.3. Some of these parts are assembled in the assembly area at one end of the powerhouse and transported by the crane to the turbo-generator pit.

The basic clearance required between the generator floor and the top of the crane rails is shown in Figures 1.2 and 1.3.

Chapter II outlines the analysis for a preliminary design of continuous crane beams, over rigid supports by using influence line diagrams, and gives the design criteria required for the analysis and design of supporting structures for overhead cranes.

Chapter III describes the use of stepped columns, and shows a method of analysis for a stepped column in structural steel.

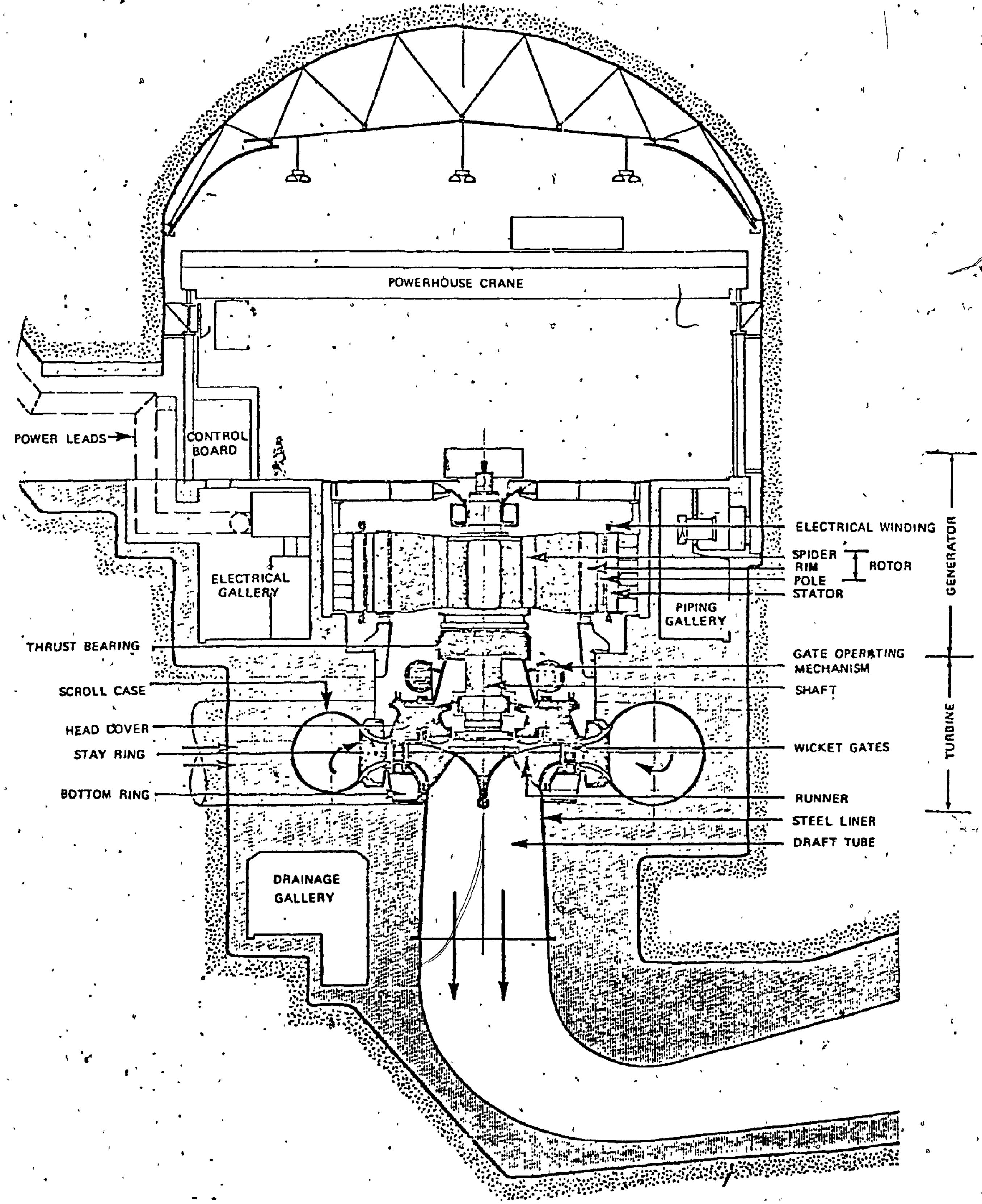

FIG. 1.1 TYPICAL CROSS-SECTION OF AN UNDERGROUND POWERHOUSE

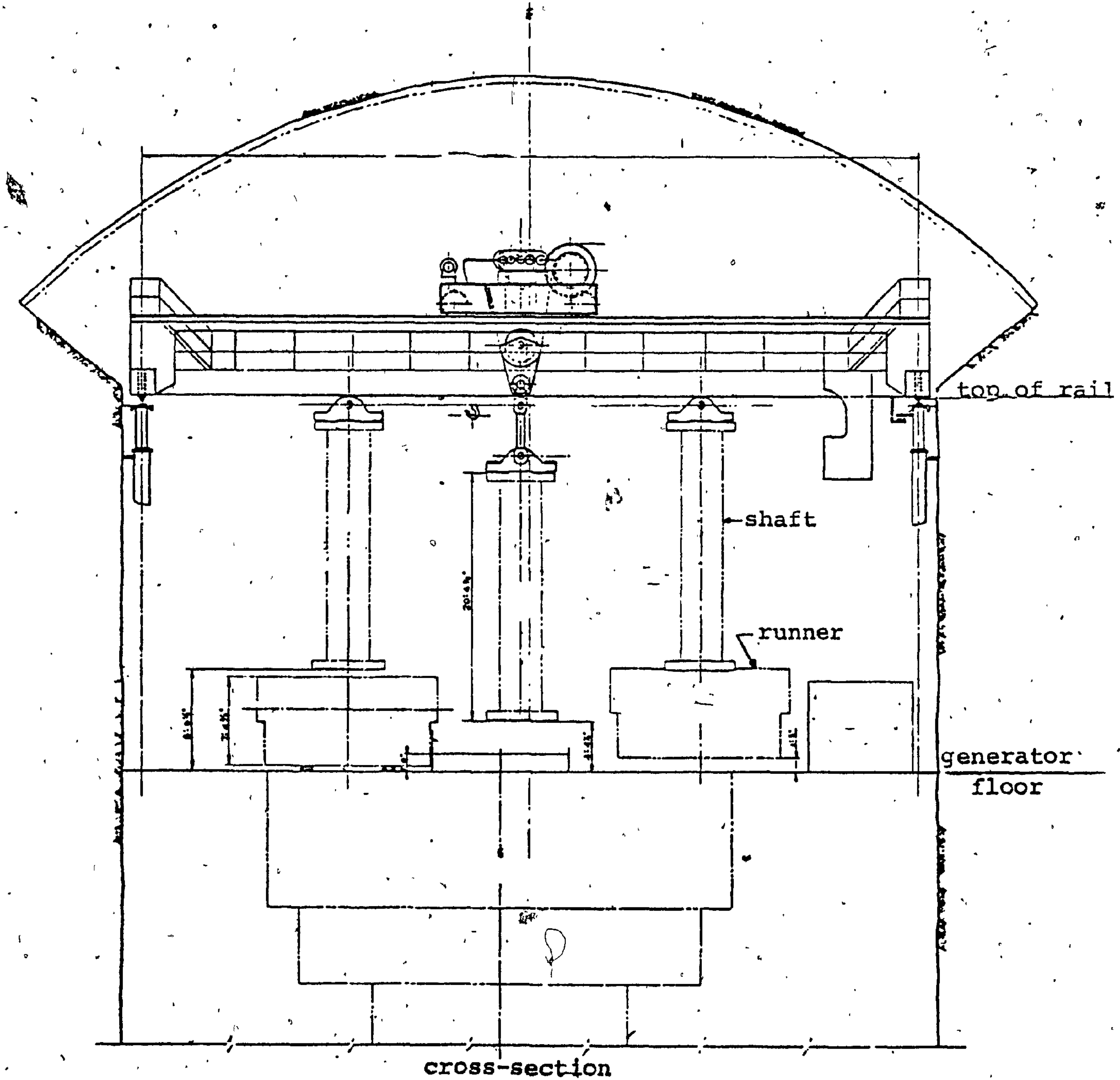

FIG. 1.2 CLEARANCE REQUIREMENT BETWEEN GENERATOR FLOOR AND TOP OF RAILS

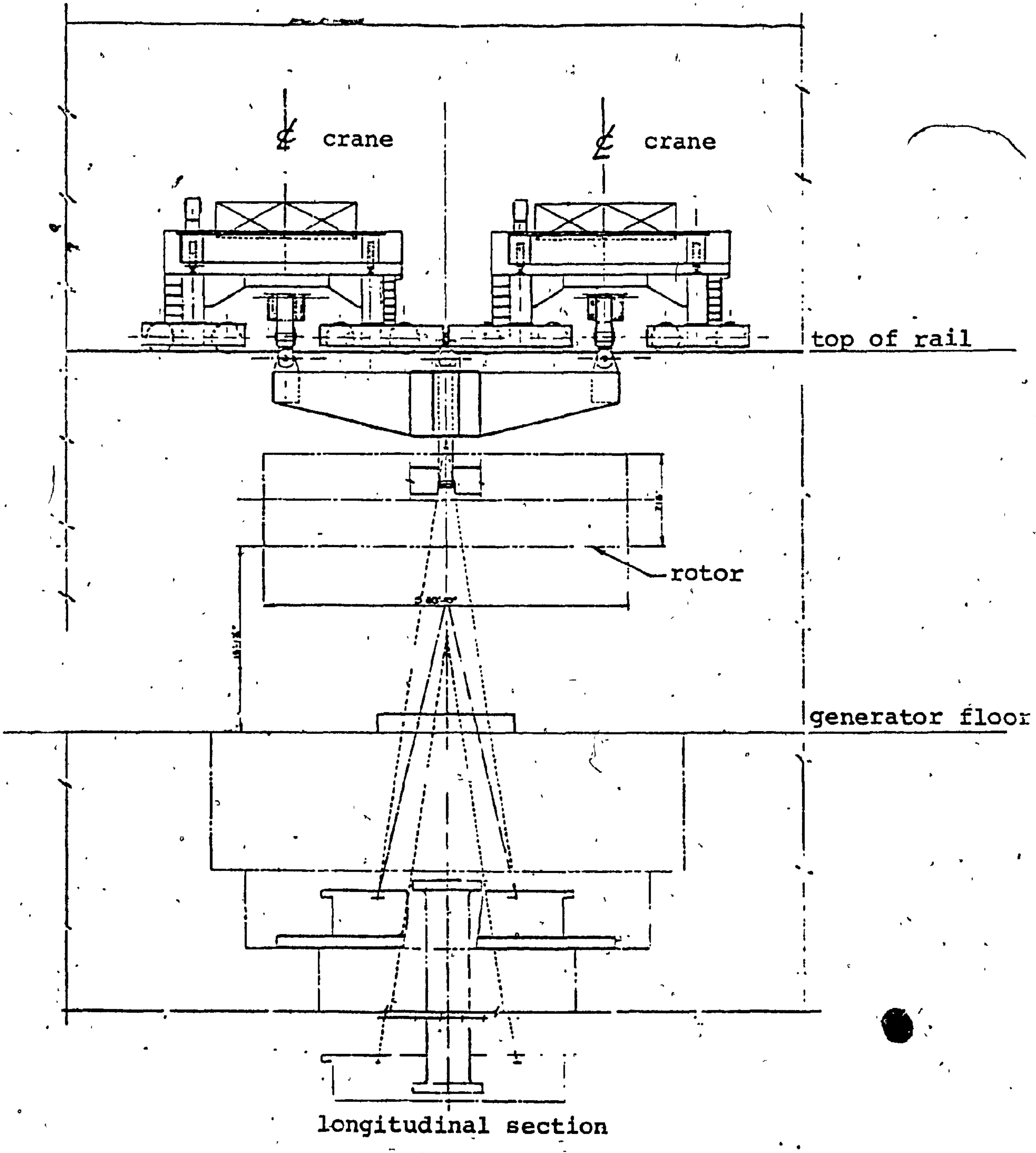

FIG. 1.3 ROTOR AND MAIN SHAFT IN DIFFERENT HANDLING POSITION

Chapters IV and V show the results of an optimization study for overhead crane supports in an underground powerhouse. Chapter IV optimizes the quantity of structural steel of crane supports for a constant total installed capacity in mega watt (MW), which is obtained by varying the number and size of the turbines, therefore obtaining different distances between the units. Chapter V optimizes the types of supports for a fixed distance between the turbo-generator units.

Chapter VI summarizes the conclusions and recommendations of this technical report.

CHAPTER II

CRANE BEAMS

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CRANE BEAMS

2.1 GENERAL

Beams supporting rails on which cranes travel are called crane beams.

Crane beams are supported by columns or brackets, depending upon the lifting capacity of the crane.

A crane with large lifting capacity requires a certain number of wheels which transfer the loads onto the rails, and then onto the beams.

Continuous crane beams are usually used in order to reduce the size of their members and the number of joints, and to simplify the connecting details at the supports. A very useful method of analysis for moving loads onto continuous beams is the use of influence-line diagrams. Influence lines show graphically, how changing the position of the loads on the beams influences the magnitude of the reactions, bending moments and shearing forces.

With the aid of an influence-line diagram, it is possible to develop general criteria to determine the most critical position of the loads in any given cases. Since the concentrated wheel loads on one rail are more than one, it is not possible, in general, to determine at once, which load of the series should be placed at the given section in order to obtain a maximum value. The method that should be followed is essentially one of trial.

2.2 USE OF INFLUENCE LINES FOR ANALYSIS OF CONTINUOUS CRANE BEAMS

The use of influence line diagrams [1] for a preliminary analysis of continuous crane beams under the action of moving loads is outlined by the following steps:

1) Drawing wheel arrangement (Figure 2.1) using the same scale of the influence line diagram related to center-to-center of supporting columns of the structure under consideration (Figure 2.2).

2) Finding the maximum positive moment, which occurs at the end span, using the wheel arrangement (Figure 2.1) and influence-line diagram (Figure A.1).

3) Finding the maximum positive moment in an interior span using wheel arrangement (Fig. 2.1) and influence line diagram (Figure A.2).

4) Finding the maximum negative moment, which occurs at the first interior support using wheel arrangement (Fig. 2.1) and influence-line diagram (Figure A.3).

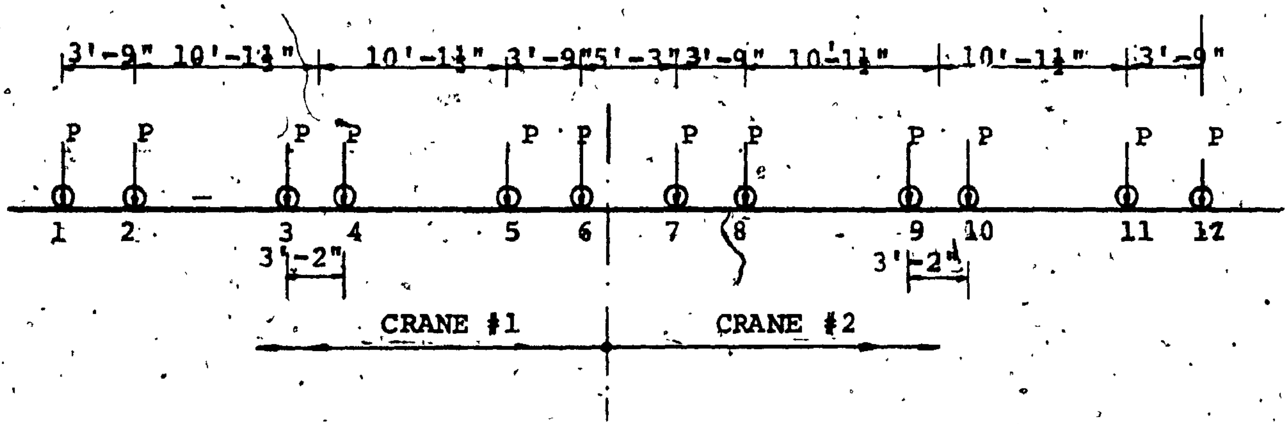

FIG. 2.1 WHEEL ARRANGEMENTS OF TWO OVERHEAD CRANES WORKING IN TANDEM

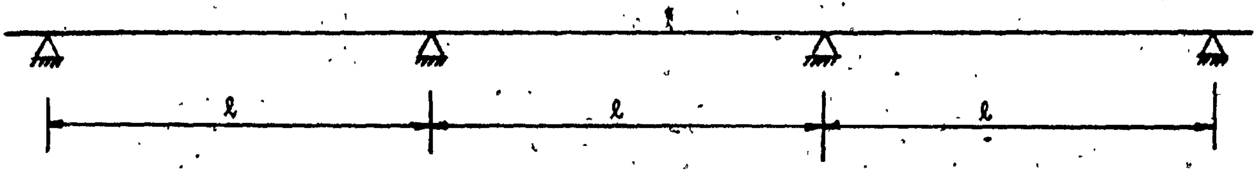

FIG. 2.2 CONTINUOUS CRANE BEAMS ON RIGID SUPPORT

5) Finding the negative moment at the interior supports, using the wheel arrangement (Figure 2.1) and influence-line diagram (Figure A.4).

6) Finding the maximum reaction which occurs at the first interior support, using the wheel arrangement (Fig. 2.1) and influence-line diagram (Fig. A.5).

7) Finding the reaction on an interior support using the wheel arrangement (Figure 2.1) and influence-line diagram (Figure A.6).

8) Finding the maximum shear, using the wheel arrangement (Figure 2.1) and the influence-line diagram, (Figure A.7).

2.3 FORMULAS AND APPLICATIONS

The general formula to find the bending moment is:

$$M = \Sigma y \times PL \qquad (2.1)$$

The general formula to find the reaction is:

$$R = \Sigma y \times P \qquad (2.2)$$

where

Σy = summation of the values of the ordinates under the concentrated wheel loads.

P = wheel load

L = span length

2.4 MAXIMUM POSITIVE MOMENT AT INTERMEDIATE SPAN

The maximum positive moment at the intermediate span for the continuous crane beam subject to a series of moving loads, is obtained using a wheel arrangement (Figure 2.1) and influence-line diagram (Figure A.1).

The spacing of columns supporting the crane beam in this case, is 22 feet center-to-center.

There are 12 wheels numbered from left-to-right on each rail for the two overhead cranes working in tandem. The relative position of the wheels, the closest distance that the main hook can get to the center-line of a rail, the weight of the crane and other data, is outlined in the Design Criteria, and is supplied by the crane's manufacturer.

The position of the moving wheel loads on the influence-line diagram and the summation of the values of the ordinates corresponding to each wheel in the diagram at a fixed position, is recorded in Table 2.1.

The maximum value is obtained when the wheel number 6 is on the center of the diagram. This value multiplied by the maximum wheel load P and by the distance L, between supports, will give the maximum positive moment for the continuous crane beam.

2.5 MAXIMUM NEGATIVE MOMENT AT AN INTERIOR SUPPORT

The maximum negative moment at an interior support for the continuous crane beam subject to the action of a series of moving loads is obtained using wheel arrangement (Figure 2.1) and influence-line diagram,(Figure A.4).

By moving the wheel arrangement over the influence-line diagram and recording the values of the ordinates as described in the previous section, Table 2.2 was obtained. This table shows the results of the trial method of positioning the moving loads over the crane beam and the summation of ordinates of the influence-line diagram corresponding at the position of the wheels at fixed positions.

It can be noted that after the maximum value was obtained, while Wheel Number 10 was on the right support of the diagram, advancing the series of loads to the right, the summation values of the ordinates decreases.

The maximum value found multiplied by the maximum wheel load P and by the distance L between the supports gives the maximum negative moment at the interior supports.

TABLE 2.1

MAXIMUM POSITIVE MOMENT AT INTERMEDIATE SPAN

WHEEL LOCATION RELATED TO INFLUENCE LINE DIAGRAM	Σy
Wheel #3 on ℄ of diagram	0.281
Wheel #4 on ℄ of diagram	0.255
Wheel #5 on ℄ of diagram	0.258
Wheel #6 on ℄ of diagram	0.304
℄ of cranes on ℄ of diagram	0.286

TABLE 2.2

MAXIMUM NEGATIVE MOMENT AT AN INTERIOR SUPPORT

WHEEL LOCATION RELATED TO INFLUENCE LINE DIAGRAM	Σy
℄ of cranes on the right support	0.2672
Wheel #7 on right support	0.2857
Wheel #4 on ℄ of diagram	0.2518
Wheel #8 at 4'-6" interior of the right support	0.3350
Wheel #8 at 6'-9" interior of the right support	0.3334
Wheel #10 on right support	0.4261
Wheel #5 on ℄ of diagram	0.3611
℄ of wheels on ℄ of diagram	0.2892

2.6 NUMERICAL VALUES

The maximum wheel load for the two cranes working in tandem (Figure 2.1) having a lifting capacity of 850 tons, is 130 kips, including static and dynamic loads.

Using the maximum values obtained from Tables 2.1 and 2.2, and Equation (2.1), the following values can be derived:

(a) Maximum positive moment at intermediate span

$$(+) \quad M_{max} = \Sigma y \times PL$$
$$= 0.304 \times 130 \times 22$$
$$= 869 \text{ K-ft}$$

(b) Maximum negative moment at an interior support

$$(-) \quad M_{max} = \Sigma y \times PL$$
$$= 0.4261 \times 130 \times 22$$
$$= 1218 \text{ K-ft}$$

Using appropriate influence line diagrams and wheel arrangement of Figure 2.1, other numerical values were obtained:

(c) Maximum reaction on first interior support

$$R = \Sigma y \times P$$

$$= 4.2923 \times 130$$

$$= 558^{K}$$

(d) Reaction on other interior support

$$R = \Sigma y \times P$$

$$= 4.270 \times 130$$

$$= 555^{K}$$

(e) Maximum negative moment on first interior support

$$(-)\ M_{max} = \Sigma y \times PL$$

$$= 0.43173 \times 130 \times 22$$

$$= 1235^{K\text{-}ft}$$

The computer program "AMECO" [2], which handles moving loads on continuous beams, was also used for the analysis of the crane beams in consideration.

The values thus obtained were very close to those derived from the use of the influence-line diagrams.

2.7 DESIGN CRITERIA

2.7.1 General

The design criteria is a series of parameters and a guideline that the engineer uses for the analysis and design of supporting structures for overhead cranes.

It specifies the structural properties of the material to be used, the codes and standards used to comply with the technical characteristics of the crane, the design loads, and the general assumptions to be taken into consideration. These are shown in the following Tables 2.3, 2,4 and 2.5.

TABLE 2.3 DESIGN CRITERIA

Material, Codes and Crane Data

Structural steel properties

Allowable stress

Codes and standards

Crane data:

- Crane capacity
- Centre-to-centre of cranes
- Rail size
- Centre-to-centre of rail
- Weight of crane, including trolleys
- Weight of main trolley
- Wheel spacing
- Maximum wheel load

TABLE 2.4 DESIGN LOAD [3]

Vertical crane load:

Static wheel loads increased by 25%.

Horizontal crane loads:

Lateral force, 10% of the lifted load plus trolley, applied at the top of one rail and acting in either direction normal to the runway rail.

Longitudinal force, 10% of maximum static wheel load, applied at top of rail.

TABLE 2.5 DESIGN ASSUMPTIONS

Assume crane beams are continuous.

Top flanges of beams are to be designed for full lateral and vertical loads acting simultaneously.

Beam-to-beam connection shall transmit longitudinal loads except at expansion joints.

Lateral loads shall be resisted at crane beam level.

Longitudinal loads shall be transmitted to the foundation by column and diagonal bracings.

Columns shall be designed for maximum loads.

Eccentricity due to thermal expansion to be considered.

To consider also additional column loads due to bracings.

CHAPTER III

STEPPED COLUMNS

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STEPPED COLUMNS

3.1 GENERAL

A stepped column supports the crane columns over a flange, see Figure 3.1.

The bending moment below the step is resisted by the lower part of the column. The upper part usually supports the roof. To transmit the bending moments from the upper part, the joint of the two-column sections must be strongly spliced.

Stepped crane columns must be designed for direct stress and bending about the major and minor axes. The variation in cross-section must be taken into account in determining the allowable axial compressive stress and the allowable bending stress. The end conditions must be considered in finding the equivalent effective length KL.

As shown in Figure 3.2, the use of separate columns has several advantages for heavy crane loads, the loads can be applied concentrically on the crane column/ Regardless of the orientation of the upper columns, the crane column can be placed with the web parallel to the crane girder, to obtain maximum resistance to the longitudinal forces. The upper columns can be independently oriented so that its strong axis can resist earthquake loads and lateral forces from the crane. But separate columns may not be economical for light loads. Hence, brackets are suitable for light loads (below 5 tons).

3.2 ANALYSIS AND DESIGN METHOD

The design of a stepped column [4] is based on an equivalent effective length of the column which is a function of the end conditions of the column.

The value of the equivalent column length factor "K" can be found using Tables E.1.I to E.1.XII [5].

To use the tables three parameters are needed:

(a) The ratio of length of the upper section to the total length of the column.

(b) The ratio of the moments of inertia, about the major axis, of the lower section to the upper section.

$\frac{P_1}{P_2}$ - The ratio of the axial force in the upper section to the axial force added to the lower section.

These tables are strictly applicable to columns for which the crane shaft is connected to the upper column by a continuous welded longitudinal web plate. However, moments approximated by assuming the integral behaviour of battened or laced columns and the column adequacy may be checked by the following procedure;for such, the interaction formula to be applied are:

$$\frac{f_a}{F_a} + \frac{C_{mx}\ f_{bx}}{(1-\frac{f_a}{f_{ex}})\ F_{bx}} + \frac{C_{my}\ f_{by}}{(1-\frac{f_a}{F_{ey}})\ F_{by}} \leq 1 \qquad (3.1)$$

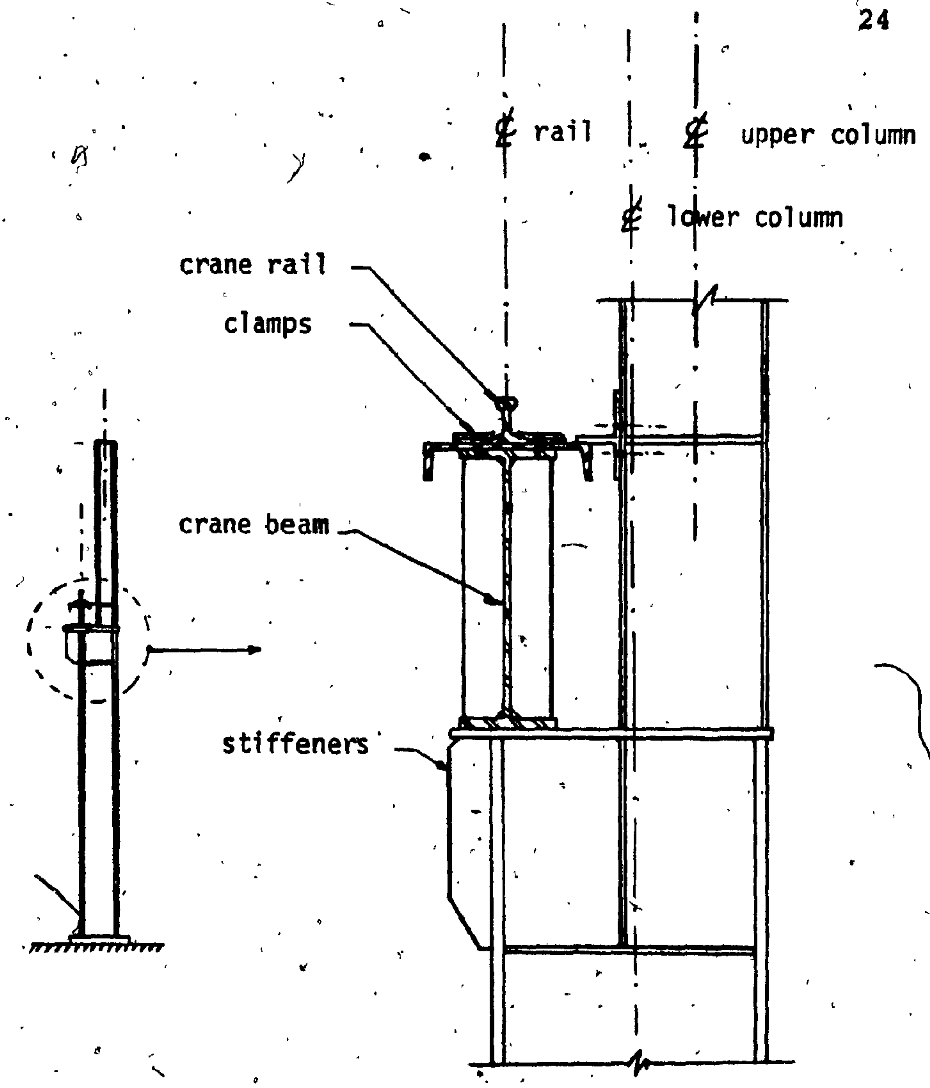
$$\frac{f_a}{0.6F_y} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1 \qquad (3.2)$$

Principal attention will be given here, to the application of Equation (3.1) to the lower segment of the column, i.e., "B-C", as illustrated in Figure 3.1. An outline summary of special considerations required in applying Equation (3.1) to this problem is as follows:

The upper segment, A-B will involve bending about only one axis (X-X).

f_a - This is the average axial stress $(\frac{P_1 + P_2}{A})$ where

A is the area of the entire cross-section, and



(a) (b)

FIG. 3.1 TYPICAL SINGLE STEPPED COLUMN AND CRANE BEAM DETAIL

P_1 and P_2 are forces applied to the two segments of the column, as shown in Figure 3.2.

F_a - This is the allowable axial stress in a centrally loaded column. It may be determined by the equivalent $\frac{KL}{R}$ of the total length, A-C, making use of Tables E.1.I to E.1.XII, for bending in the plane of the bent, about (X-X) or it may be determined by bending about (Y-Y) for whatever column length is unsupported by the column line or wall framing.

For bending about (X-X), Tables E.1.I through E.1.VI, [5], assume a hinge at the base C and Tables E.1.VII through E.1.XII, [5], assume the base fully fixed. In this case, F_a will be determined by bending about the (Y-Y) axis. If support in the (X-X) axis is provided only at locations A,B and C, the unsupported length B-C should be taken as "L" and if the base at "C" can be considered fully fixed by the footing for bending about the (Y-Y) axis, then "K" should be taken as 0.8. If less than full rotational restraint is provided by the footing for bending about the (Y-Y) axis, "K" may be assumed equal to 1.0.

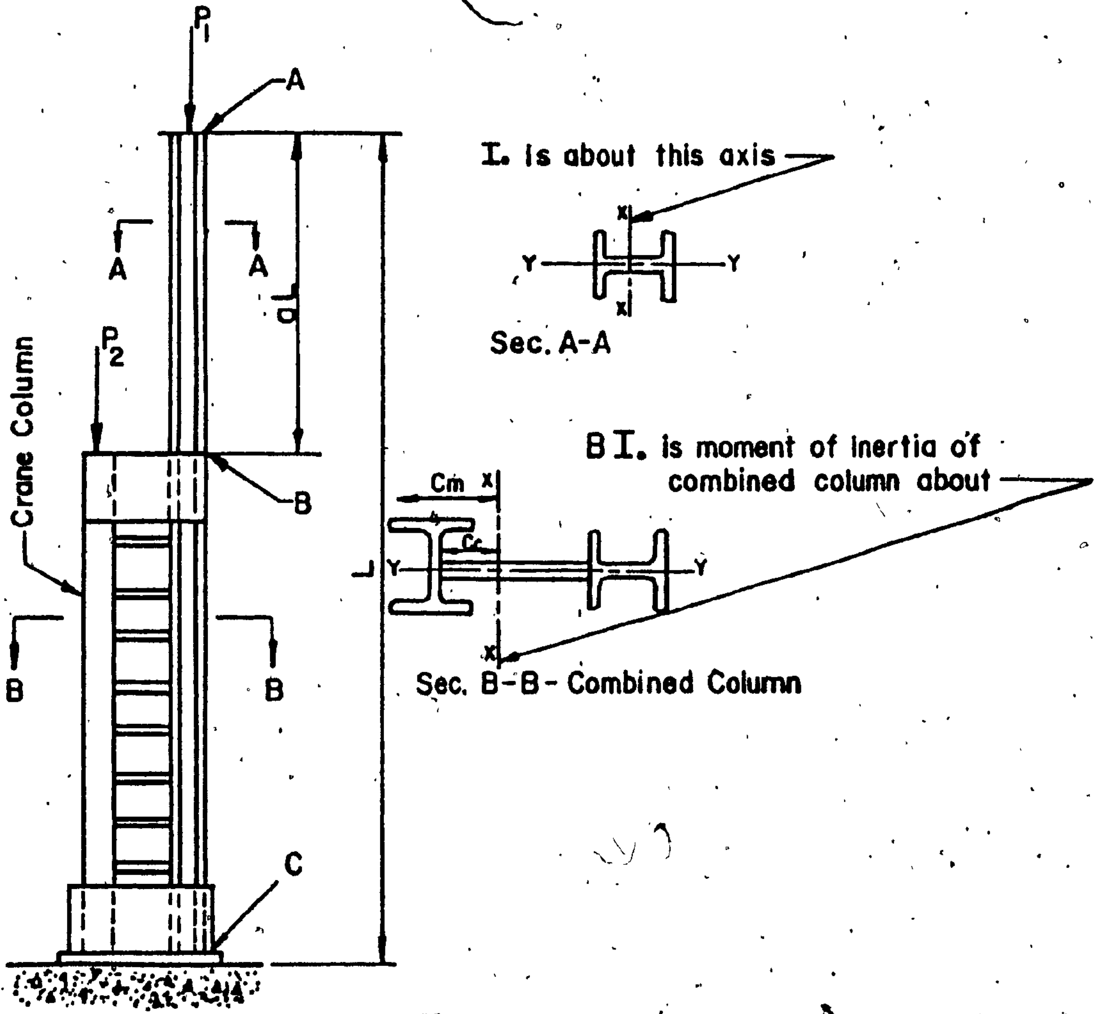


FIG. 3.2 COMBINED CRANE COLUMN

C_{mx} - For bending in the plane of the bent, about (X-X), assume a value of 0.85 when all bents are under simultaneous loads and sideways is assumed to take place. When one bent is being considered, under maximum crane loading, assume a value of 0.95 for C_{mx}.

f_{bx} - Maximum stress due to bending about (X-X) axis.

F_{bx} - For compression on the crane column side, F_{bx} would be the permissible edge fiber stress due to bending. The stress reduction may be based upon the permissible axial stress in the crane column, acting as a column in bending about the (Y-Y) axis, as shown in Figure 3.2.

The (Y-Y)-axis in Figure 3.2 would correspond to the (X-X)-axis of the individual crane column if a rolled section were used. The permissible column stress, so determined, should be multiplied by the ratio C_m/C_c as defined by Section B-B. Figure 3.2, if this stress is greater than 0.6 F_y, the smaller of the two should be taken as F_{bx}.

F'_{ex} This stress is used to determine the increase of the bending moment, as the result of column deflection in the plane of bending, and it should be based upon the equivalent length of the complete column, (as previously determined for the evaluation of F_a) bent about (X-X)-axis.

Rotational restraint is provided by the footing for bending about the (Y-Y) axis.

C_{my} - In determining this coefficient, as well as the value of all other parameters in the third term of Equation (3.1), only the crane column is assumed to be effective. It should usually be assumed as not rotationally restrained at the top (at B), but is supported against the joint translation longitudinally at the same location. Although not restrained, bending due to eccentric loading can be introduced at "B". At the base, it usually may be assumed fixed unless footing conditions are poor. Assuming no interaction with the upper column, half of the moment introduced at "B", as the result of unequal reactions on adjacent beam spans will be carried over to the base, in which case, $C_{mx} = 0.4$. If the base fixity at "C" of the crane column cannot be assumed, take $C_{mx} = 0.6$ (hinged condition) or interpolate between 0.4 and 0.6.

f_{by} - Maximum stress due to bending about (Y-Y)-axis in crane column segment (See C_{my}).

F_{by} - This component of bending is about the weak axis of the combined columns and no reduction in the permissible stress need be made for lateral buckling. Also, since the bending resistance is considered to be provided solely by the crane column, the stress may be that permitted in a compact section, if a rolled section that meets the special requirements is used.

F'_{ey} - If the base can be assured as fixed, assume K = 0.8 for the crane column alone, otherwise, assume K = 1.0. The length would be that of the crane column segment B-C.

f'_a - This is the average axial stress in the crane shaft component of the lower cross-section of the crane column and should be determined ~~as~~ the average stress in the crane column segment, instead of the average stress f_a of the total section.

CHAPTER IV

CRANE SUPPORTS IN AN UNDERGROUND POWERHOUSE

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CRANE SUPPORTS IN AN UNDERGROUND POWERHOUSE

4.1 GENERAL

An underground hydroelectric powerhouse generally includes:

a) An access tunnel which leads to one end of the powerhouse.

b) An area at the level of the generator floor with direct access for trucks to unload the material, heavy equipment and machineries.

c) An area for the assembly of the rotor and other major parts of the turbo-generator units at the other end of the powerhouse.

d) A series of turbo-generator units.

e) Areas for electrical and mechanical shops and services.

f) A system of overhead running cranes.

Once the size and number of turbines and the maximum load and height of the rotor have been established, or tentatively proposed, the size of the machine hall can then be defined. This will dictate the ov[illegible] span of the crane bridge, i.e., the distance from t[illegible]enter-line to center-line of the rails, and therefore, the location of the crane beams and column lines.

Another equipment to consider in establishing the height between the top of the rails and the generator floor is the main shaft (Figures 1.1 and 1.2). The main shaft which is the link between the turbine's runner and the generator's rotor can be in one piece or spliced. The one-piece shaft is assembled with the runner of the turbine; if spliced, the upper shaft is assembled with the rotor and the lower shaft is assembled with the runner.

4.2 OPTIMIZATION OF SUPPORTING STRUCTURES FOR OVERHEAD CRANES

Once a certain number of Mega Watt (MW) has been established as the optimum installed capacity for a hydroelectric project, an overall optimization is necessary in order to minimize the total cost of the project.

One part of this optimization is related to the cost of the supporting structures of the overhead cranes.

Keeping approximately constant the total number of MW and varying the size and number of turbines (Table 4.1), there are changes in the length, width and height of the machine hall, in the length of the main shaft, etc.

All the above parameters are part of the optimization study.

A turbine's characteristics for a specific project are supplied by their manufacturers.

Table 4.2 shows the variation between the number and different sizes of turbines, the weight and type of corresponding rotors, the distances between the center lines of the machines and the overall lengths of the powerhouse.

TABLE 4.1 A COMPARISON OF THE NUMBER OF TURBINES AND THEIR CAPACITY

SCHEME	NO. OF TURBINES	MW PER TURBINE	TOTAL MW
A	8	551	4,408
B	9	490	4,410
C	11	400	4,400
D	14	320	4,480
E	16	312	4,992

TABLE 4.2 VARIATION OF SIZE AND NUMBERS OF TURBINES VERSUS THE LENGTH OF THE POWERHOUSE

NUMBER OF TURBINES	WEIGHT OF ROTOR (TONS)	TYPE OF ROTOR	DISTANCE BETWEEN CENTERS OF MACHINES (FEET)	LENGTH OF POWERHOUSE (FEET)
8	1625	A	93	1209
9	1375	B	87	1255
11	1320	C	86	1374
14	850	D	85	1409
16	800	E	82	1603

It can be seen that for a constant installed capacity of approximately 1440 MW by increasing the number of the turbines, therefore reducing the size and the distance between them, the length of the powerhouse increases, and so does the length of the supporting crane structures.

At the same time, the distance between the center-lines of the crane rails decreases, since for a smaller turbine, a narrower powerhouse is needed, hence a reduction in cost for the overhead crane is to be considered in the evaluation of the crane-supporting structures.

Table 4.3 shows the relationships between the weight of the rotor, the number and spacing of the crane wheels, the distance between the supports of the beams, the maximum design moment of the girder, and the maximum reaction on the supports.

The larger the size of the turbine, the bigger is the generator and therefore, the heavier is its rotor. Consequently, the lifting capacity of the crane needs to be increased and so does the number and crane wheel loads.

The spacing of the columns for the crane beams also varies according to the distance between the center-lines of the machines. An elevation of the supporting steel elements is shown in Figure 4.1.

TABLE 4.3 MAXIMUM REACTIONS AND MOMENTS INDUCED BY WHEEL LOADS FOR DIFFERENT WEIGHTS OF ROTORS

ROTOR TYPE	WEIGHT OF ROTOR (TONS)	NUMBER OF CRANE WHEELS (EACH SIDE)	WHEEL LOAD (KIPS)	SPANS OF CONT. BEAMS	MAX.NEG. MOMENT (FT-KIP)	MAXIMUM REACT. (KIPS)
A	1,625	20 @ 4'-3"	154	31'-0"	3,659	1,555
B	1,375	16 @ 4'-3"	154	24'-1½"	3,580	1,453
C	1,320	16 @ 4'-0"	150	27'-0"	3,160	1,366
D	850	16 (FIG.2.1)	130	28'-4"	2,235	1,058
E	800	16 (FIG.2.1)	130	23'-0"	1,350	710

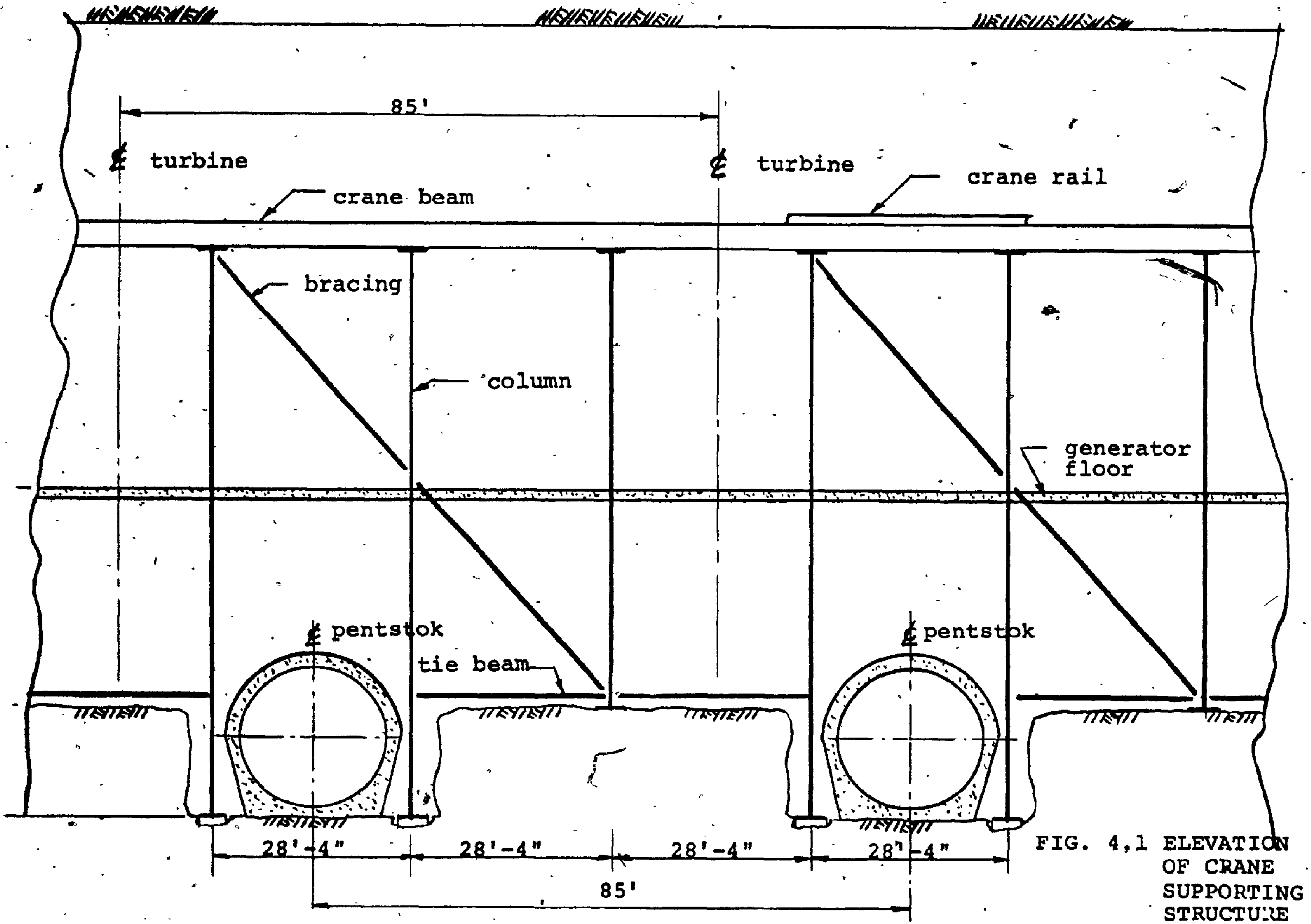

FIG. 4.1 ELEVATION OF CRANE SUPPORTING STRUCTURE

For the five different distances between center-lines of the machines of Table 4.2 equal spans were used for the preliminary analysis and the design of the crane supporting structures for the comparative quantities and cost estimate.

The influence line diagrams were used (as described in Chapter II) for the five systems of continuous crane beams and column spacings for the number and wheel loads, shown in Table 4.3. The corresponding maximum negative moments and maximum reactions for which the crane beams and columns are designed decrease considerably as the weight of the rotor decreases.

Table 4.4 shows the size of the welded-wide flange sections of the beams and columns, the tons of steel required for each of the components of the structural supporting system and the total tonnage of structural steel for the five alternatives.

A total preliminary design for the whole supporting structures was done and repeated for the five different types of rotors.

Crane beams were selected taking into account the moments and shears induced by vertical wheel loads, as well as the longitudinal breaking forces in the direction of the rails.

TABLE 4.4 COMPARISON OF MEMBERS FOR STRUCTURES SUPPORTING ROTORS OF VARIOUS WEIGHTS

ROTOR TYPE (TONS)	STRUCTURAL STEEL G10.12 ALGOMA (TONS)							
	BEAMS	COLUMNS	BEAMS	COLUMN	RAIL	PLATES	TIES AND BRACINGS	TOTAL TONS
A (1625)	48WWFS320 + 72 #/1	18WWF 267	472	691	70	70	166	1,469
B (1375)	48WWFS320 + 72 #/1	18WWF 237	492	692	73	76	148	1,481
C (1320)	48WWFS299 + 72 #/1	18WWF 208	514	713	80	90	166	1,563
D (850)	48WWFS236 + 58 #/1	16WWF 178	381	498	82	73	127	1,161
E (800)	33WWF 201 + 58 #/1	14WWF 116	415	427	91	111	132	1,176

For the purposes of the comparative estimate of quantities, it was assumed that the horizontal forces perpendicular to the crane rails were to be resisted by the rolled channel resting on the top of the crane beams.

The possibility providing support to the beams for lateral stability at mid-span by the use of rock bolts was also considered in selecting the most economical sections.

Columns were also designed for the maximum beam reaction including forces transmitted by the longitudinal diagonal bracings for the five structures supporting rotors of various weight.

The unsupported length of the columns was reduced in one direction by the use of tie beams and in the other direction by using rock bolts at different heights.

The weight of the rails increased with the length of the powerhouse and so did the weight of the tie beams and base plates.

The total tonnage of steel decreased considerably for the supporting structures of the smaller overhead crane-lifting capacities.

Supporting structures for overhead crane-lifting rotor type "D" required the minimum amount of structural steel.

It should be noted that the beams and columns for the supporting structure for the overhead crane-lifting rotor type "E" are, in fact, lighter than those for type "D". But, since the powerhouse is about 200 feet longer, because it has to accomodate two extra turbines, the amount of structural steel required is more than that used for Type "D".

CHAPTER V

TYPES OF CRANE SUPPORTS

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TYPES OF CRANE SUPPORTS

5.1 GENERAL

This part of the report is considered as a second stage optimization process for the supporting structures of overhead cranes in an underground powerhouse.

In Chapter IV, the optimization of the crane supporting structures was related to the number and size of the turbine; here it is related to the types of supports of the overhead cranes for an accepted number of turbines, and for a fixed distance between the center-lines of the turbines, thus, a defined length, height and width of the powerhouse.

This study is based on a powerhouse with the following characteristics:

Length	1,410 ft.
Width	90 ft.
Center-to-center of rails	85 ft.
Center-to-center of turbines	85 ft.
Maximum weight of rotor	850 t.

The weight of the rotor suggests the use of two cranes working in tandem with a lifting capacity of 425 tons each. A third crane of 35 tons capacity is also included in this study. This small crane is required during construction time, mainly to carry bundles of reinforcing steel bars and concrete to be poured into the lower part of the draft-tube and around the scroll case well before the erection of the larger cranes which are not suitable for this type of work due to their low speed.

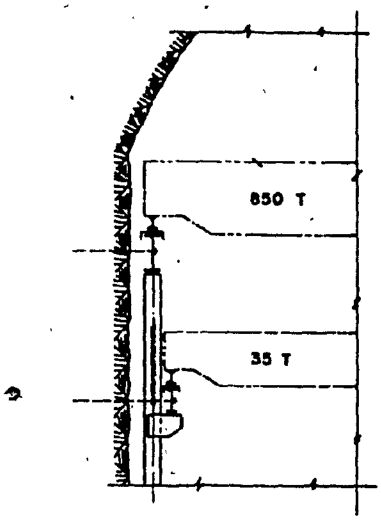
This construction crane does not interfere with the operation of the two larger cranes, therefore, it is placed at a lower level as shown in Figure 5.1.

The arrangement of the wheels for the two cranes working in tandem is shown in Figure 2.1.

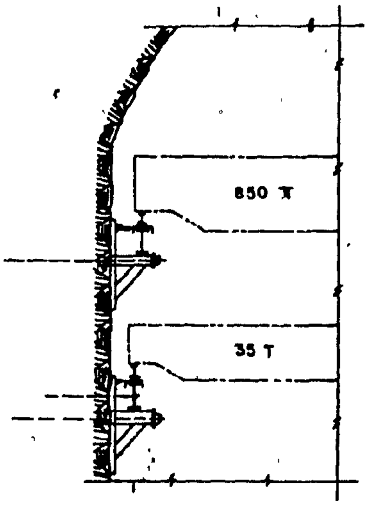
5.2 SUMMARY

Three practical systems of crane supports have been considered (a) columns and girders, (b) brackets post-tensioned to rock and (c) rock shoulder. The following five alternatives were developed from these three systems:

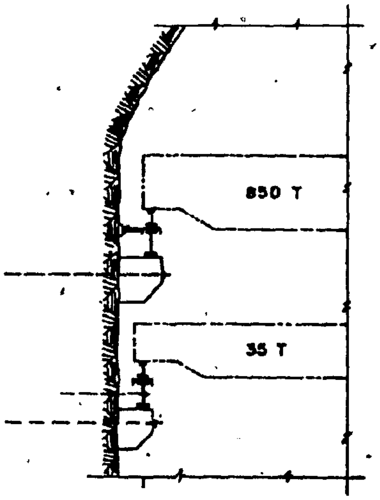
Alternative 1	Structural Steel
Alternative 2	Steel Brackets
Alternative 3	Concrete Brackets
Alternative 4	Rock Shoulder
Alternative 5	Reinforced Concrete



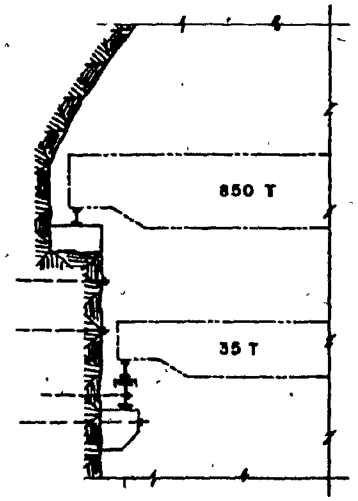
Alternative 1 - Structural Steel



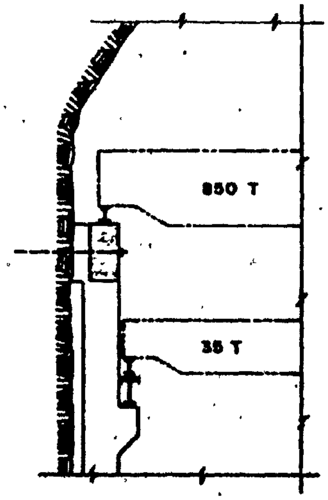
Alternative 2 - Steel Brackets



Alternative 3 - Concrete Brackets



Alternative 4 - Rock Shoulders



Alternative 5 - Reinforced Concrete

FIG. 5.1 ALTERNATIVES OF OVERHEAD CRANE SUPPORTS FOR UNDERGROUND POWERHOUSE

The supporting structure was designed for each of the five alternatives, considering also the construction methods and the working schedules. The details of the supporting structures for the five alternatives are shown in Figure 5.1.

A summary of the comparison cost analysis is presented in Table 5.1, on page 50, showing the quantities and cost of materials for five alternatives of the supporting structures for the same system of overhead cranes.

The major items taken into consideration are: reinforced concrete structural steel, post-tension cables, rock bolts, differential rock excavation and differential cost of overhead cranes due to the larger span of alternative 4.

5.3 DESCRIPTION OF ALTERNATIVES

5.3.1 Alternative 1 - Structural Steel

This Alternative which is the more frequently used in powerhouses, is shown in Figure 5.1. An elevation showing a similar arrangement of steel columns and crane beams was presented in Chapter IV, Figure 4.1.

In Alternative 1, the steel columns are sitting on concrete pedestals, which are bearing upon solid rock; the height of the columns varies from 55' to 85' and their spacing is 28'-4" center-to-center, thus providing equal span for the crane beams.

Continuous steel beams are resting on top of the columns providing the runway for the two large cranes.

The 35-ton construction crane runs at a lower level over rolled steel beams supported by steel brackets attached to the columns.

5.3.2 Alternative 2 - Steel Brackets

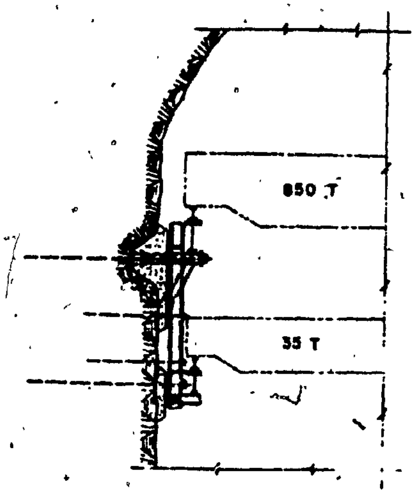
The Steel Bracket Alternative, shown in Figure 5.1, consists of preassembled steel brackets, post-tensioned to the powerhouse rock wall.

The continuous crane beams are sitting on the brackets and are laterally supported by additional rock anchors.

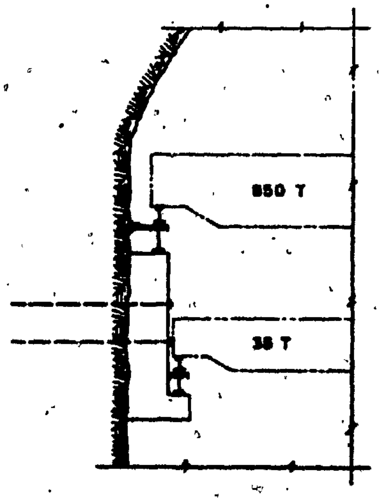
Diagonal members are also provided to transfer the crane's longitudinal breaking forces to the rock wall.

An optimization study for this alternative shows that the most economical spacing of the brackets is 16 feet, center-to-center. In this case, a spacing of 17 feet was chosen in order to be within the module of 85 feet which is the spacing between the centers of the turbines.

The possibility of having one bracket supporting the three cranes was also considered and Figure 5.2(a), showing



VARIANT ② A
Steel Bracket (a)



VARIANT ③ A
Concrete Bracket (b)

FIG. 5.2 ALTERNATIVES OF OVERHEAD CRANE SUPPORTS FOR UNDERGROUND POWERHOUSE its general arrangement is presented here, as an illustration only since it was not included in the optimization analysis of the alternatives.

5.3.3 Alternative 3 - Concrete Brackets

This alternative, shown in Figure 5.1, is similar to the previous one, except that the two brackets are made of reinforced concrete.

The possibility of a combined single bracket was considered and Figure 5.2(b) shows it in detail. Here also, the optimal spacing of the brackets was investigated and chosen at 17 feet center-to-center.

5.3.4 Alternative 4 - Rock Shoulder

This type of crane support, shown in Figure 5.1, has been used lately in various underground hydroelectric powerhouses.

A recess on the top of the rock wall is provided by using an accurate control of the excavation line. A continuous reinforced concrete base over this rock shoulder supports the rails of the large lifting capacity cranes. The distance between the center lines of the rails for this alternative is therefore increased.

Additional rock bolts are required to stabilize the rock wedge under the shoulders.

The construction crane is supported by independent brackets post-tensioned to the rock wall as that done for Alternative 3.

5.3.5. Alternative 5 - Reinforced Concrete

This alternative which is shown in Figure 5.1, has the same characteristics of Alternative 1, except that the columns and crane beams are in reinforced concrete.

The columns are bearing directly on solid rock and are supported laterally at the top by rock anchors; in the longitudinal direction the crane beams and columns form a rigid frame structure.

TABLE 5.1 COMPARISON OF FIVE TYPES OF SUPPORTING STRUCTURES FOR BRIDGE CRANES

				ALTERNATIVES									
				STRUCTURAL STEEL		STEEL BRACKETS		CONCRETE BRACKETS		ROCK SHOULDERS		REINFORCED CONCRETE	
ITEM	DESCRIPTION	UNITS	UNIT PRICE $	QUANTITY	COST $ 10³	QUANTITY	COST $ 10³	QUANTITY	COST $ 10³	QUANTITY	COST $ 10³	QUANTITY	COST $ 10³
-	2 OVERHEAD CRANES 425 T.												
1	RAILS	TONS	1000	82	82.0	82	82.0	82	82.0	82	82.0	82	82.0
2	STEEL GIRDERS	T	900	380	342.0	231	207.9	231	207.9	-	-	-	-
3	STEEL COLUMNS	T	905	495	448.2	-	-	-	-	-	-	-	-
4	STEEL BRACKETS	T	1200	-	-	223	267.6	-	-	-	-	-	-
5	BRACINGS	T	880	100	88.2	-	-	-	-	-	-	12	10.6
6	STEEL TIE BEAMS	T	10	10.2	-	-	-	-	-	-	-	-	-
7	BEARING PLATES	T	900	73	65.7	35	31.5	14	12.6	50	45.0	50	45.0
8	CONCRETE GIRDERS	C.Y.	225	-	-	-	-	-	-	-	-	1900	427.5
9	CONCRETE COLUMNS	C.Y.	210	390*	81.9	-	-	-	-	-	-	2200	462.0
10	CONCRETE BRACKETS	C.Y.	225	-	-	-	-	1350	303.8	-	-	-	-
11	MASS CONCRETE	C.Y.	70	-	-	1200	84.0	750	52.5	1500	105.0	-	-
12	CONCRETE SLAB ON ROCK SHOULDER	C.Y.	190	-	-	-	-	-	-	1550	294.5	-	-
13	CONCRETE BASES	C.Y.	120	200	24.0	-	-	-	-	-	-	200	24.0
14	POST-TENSION CABLES 390 KIPS x 45' LONG.	FT.	40	-	-	7560	302.4	7560	302.4	-	-	-	-
15	POST-TENSION CABLES 324 KIPS x 40'	FT.	35	-	-	6720	235.2	6720	235.2	-	-	-	-
16	ROCK BOLTS 45 KIPS x 12' LONG.	FT.	10	10140	101.4	-	-	2880	28.8	2880	28.8	10140	101.4
17	ROCK BOLTS 30 KIPS x 10' LONG.	FT.	8	6800	54.4	-	-	-	-	24600	196.8	6800	54.4
18	ROCK BOLTS 15 KIPS x 6' LONG.	FT.	6	-	-	2700	16.2	2700	16.2	-	-	-	-
19	ADDITIONAL ROCK EXCAVATION	C.Y.	15	-	-	-	-	-	-	6825	102.4	-	-
20	ADDITIONAL COST OF OVERHEAD CRANES	-	-	-	-	-	-	-	-	-	85.0	-	-
	TOTAL				1313.0		1226.8		1232.8		940.7		1207.1
-	OVERHEAD CRANE 35 TONS												
1	RAILS	T	1000	40	40.0	40	40.0	40	40.0	40	40.0	40	40.0
2	STEEL GIRDERS	T	900	217	195.3	136	122.4	136	122.4	136	122.4	217	195.3
3	STEEL BRACKETS	T	1200	15	18.0	17	20.4	136	122.4	136	122.4	217	195.3
4	BRACINGS	T	900	4	3.6	-	-	-	-			4	3.6
5	BEARING PLATES	T	900	-	-	16	14.4	7	6.3	7	6.3	6	5.4
6	CONCRETE BRACKETS	C.Y.	225	-	-	-	-	130	29.3	275	61.9	100	22.5
7	MASS CONCRETE	C.Y.	70	-	-	-	-	-	-	350	24.5	-	-
8	ROCK BOLTS 45 KIPS x 12' LONG.	FT.	10	3500	35.0	-	-	-	-	4050	40.5	3500	35.0
	TOTAL				301.0		206.2		207.0		304.6		310.0
	GRAND TOTAL				1614.0		1433.0		1439.8		1245.3		1517.1

* CONCRETE COVER AROUND THE BOTTOM OF STEEL COLUMNS

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 GENERAL

From the optimization process of the supporting structures for overhead cranes in underground hydroelectric powerhouses, which has been the object of this report, the following basic conclusions can be made:

a) The reduction of the size of the turbo-generator units, therefore increasing the number of turbines and the total length of the powerhouse, while keeping constant the total installed capacity (total number of Mega Watts), the overall quantity of the structural steel required decreases.

b) For a given number and size of turbo-generators, which implies an overhead crane of a given lifting capacity, the most economical supporting structural system is the rock shoulders.

This system is also the one that can be built and be ready for use long before any other type of support.

c) The most economical supporting structures for the construction crane of 35-tons lifting capacity is, the one which consists of continuous steel crane beams supported by concrete brackets post-tensioned to rock and spaced at 17 feet center-to-center.

APPENDIX A

INFLUENCE-LINE DIAGRAMS USED FOR THE PRELIMINARY ANALYSIS OF CONTINUOUS CRANE BEAMS ON RIGID SUPPORTS - [1]

APPENDIX A

INFLUENCE-LINE DIAGRAMS USED FOR THE PRELIMINARY ANALYSIS OF CONTINUOUS CRANE BEAMS ON RIGID SUPPORTS [1]

The influence-line diagrams reproduced in this Appendix from Reference [1], were used for the preliminary analysis of continuous crane beams on rigid supports.

The method for using such diagrams consists in drawing the series of the moving loads using the same scale on the diagrams; then starting from one side, the series of wheels are moved over the diagram until the last wheel reachs the end support. By adding up the total values of the ordinates corresponding to the position of each wheel on the diagram, a maximum numerical value is obtained. This is the Σy used in the equations described in Chapter II.

The number of influence-line diagrams used here was limited to those which give the maximum values for positive and negative bending moments, reactions and shear. Since the preliminary design to estimate the quantities was on a comparative basis only and since the size of this type of crane beam is generally kept constant through its total length, the maximum values derived from the use of these diagrams were considered to be adequate.

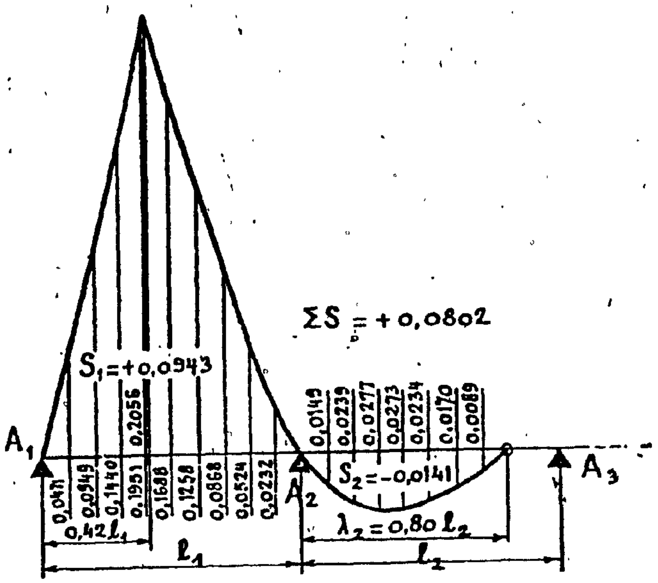


FIG. A.1 INFLUENCE LINE FOR BENDING MOMENT AT THE END SPAN

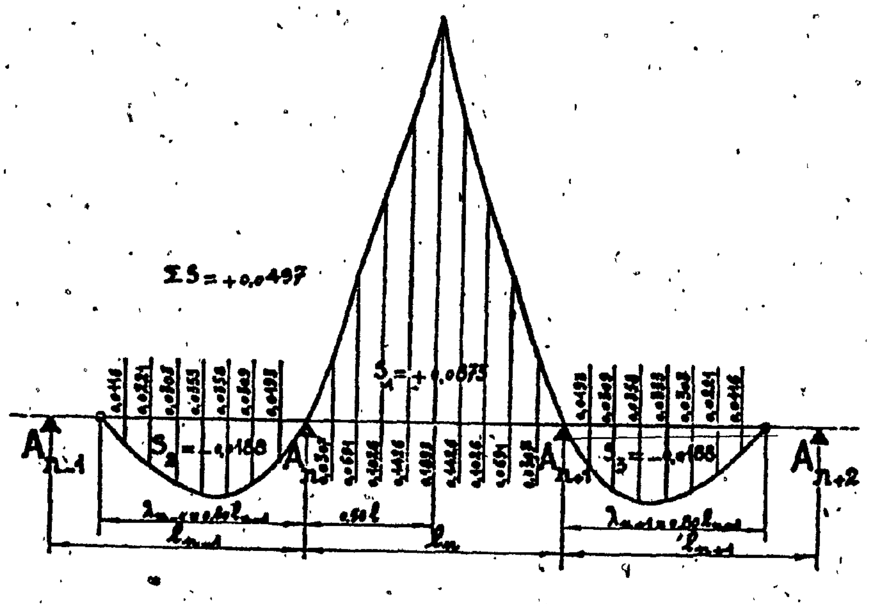


FIG. A.2 INFLUENCE LINE FOR BENDING MOMENT AT AN INTERIOR SPAN

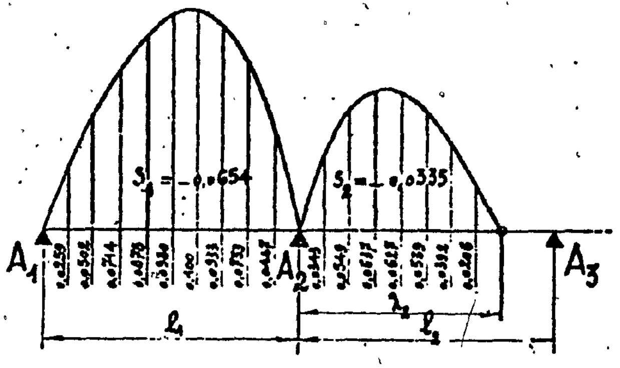


FIG. A.3 INFLUENCE LINE FOR BENDING MOMENT ON THE FIRST INTERIOR SUPPORT

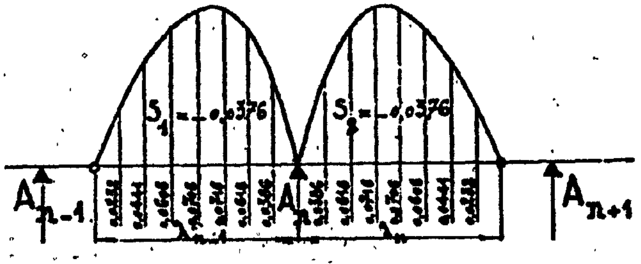


FIG. A.4 INFLUENCE LINE FOR BENDING MOMENT AT AN INTERIOR SUPPORT

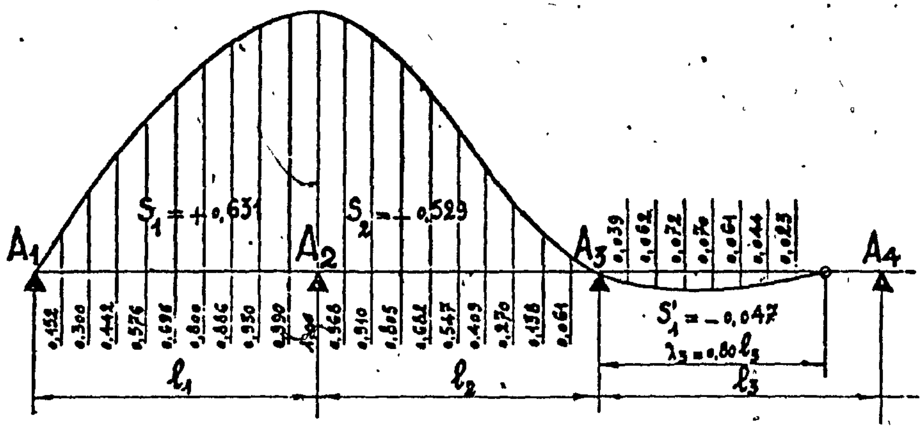


FIG. A.5 INFLUENCE LINE FOR REACTION ON THE FIRST INTERIOR SUPPORT

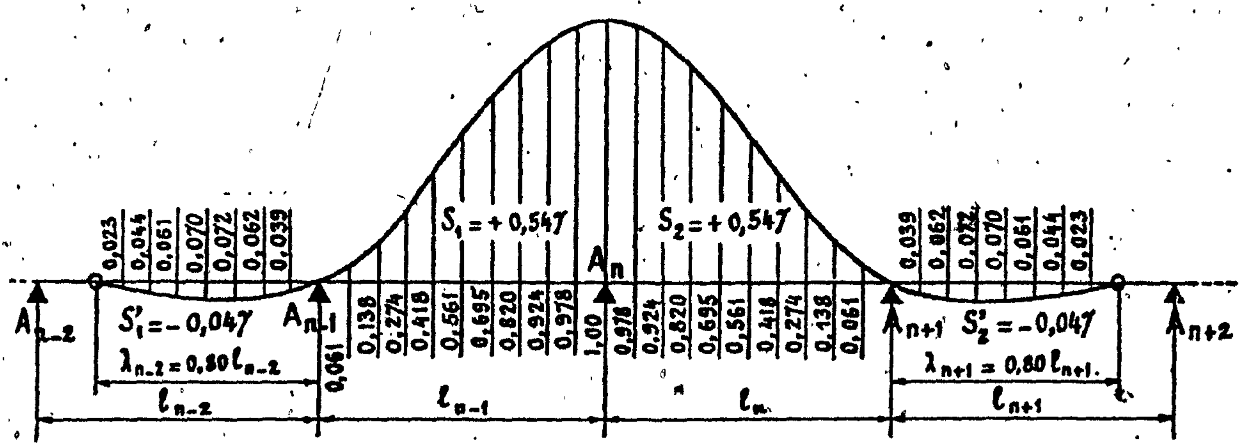


FIG. A.6 INFLUENCE LINE FOR REACTION ON AN INTERIOR SUPPORT

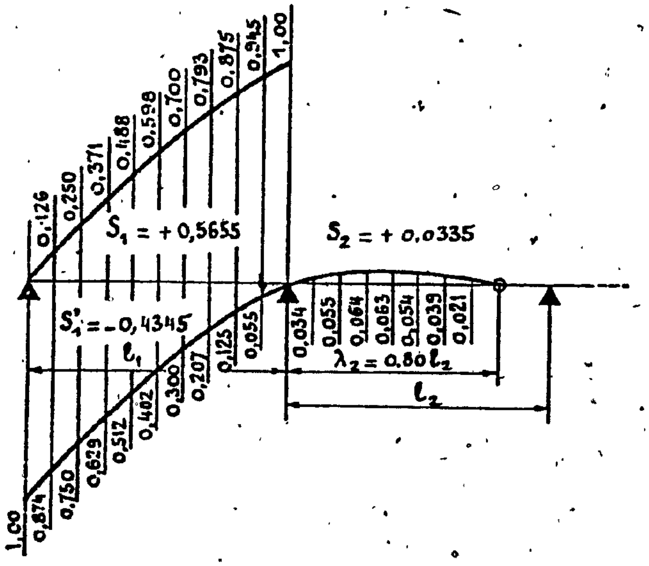


FIG. A.7 INFLUENCE LINE FOR SHEAR AT THE END SPAN

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REFERENCES

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