INNOVATIVE METHODOLOGY TO CONTROL SEEPAGE OF PATHAZHAKKUNDU EARTHEN DAM IN KERALA, INDIA

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ABSTRACT

This paper explains an innovative methodology used to control seepage around outlet duct of well intake in Pathazhakkundu earthen dam in Kerala, India. The dam showed distress due to aging after two and half decades of it's commissioning in 1978. For the past twelve years, it was not possible to fill water up to full reservoir level (FRL) and its intended purpose was not served. This was mainly due to seepage in the outlet barrel opened to the distribution canal. Many attempts were made to control this seepage but were ineffective. Repairing a very long barrel duct with small cross-sectional area was a challenge. This was overcome with an innovative construction method closely like the push technology. In this paper, we are presenting this method together with its replicability scope in repairing similar dams. Details of the post construction analysis taken up to simulate and verify the structural stability of the duct are also presented. At present, the hydraulic and structural parameters, governing this dam are within safe limits and it is possible to fill the water up to FRL.

1. INTRODUCTION

Pathazhakundu Dam is an earthen dam in Thekkumkara Grama Panchayath under Minor Irrigation Division Thrissur located at Pathazhakundu 21 Kms away from Thrissur and 8kms near to Wadakkanchery in Kerala in southern India. This Dam was commissioned during 1978. This dam is intended to supply irrigation water which benefits an ayacut of 150.70Ha.The dam is more than 40 years old and which was not effectively functional since early 90's due the lack of proper maintenance works after the commissioning of the project. The RR masonry barrel, well sluice, joints between masonry walls, pre-cast roof concrete slabs of barrel were all in a dilapidated condition which resulted severe seepage of water through the barrel and dam body. The Rip rap (Stone pitching) in the upstream face of the dam was sinked at several places de-shaped and loosened. Whirlpools were also observed on upstream when the reservoir was getting full. All the defects mentioned above were rectified to a greater extent by executing works costing Rs: 208.50 Lakhs in the year 2014-15. Still, severe leakage has been noticed in the dam body and further rectification works such as bentonite grouting at downstream portion and non-shrink grouting inside the sluice well has been carried out for arresting leakage from the dam body to arrest the leakage.

It is also observed that internal erosion of the foundation or embankment caused by seepage which is generally starts at the downstream toe and works back towards the reservoir forming channels or pipes under the dam. This can be avoided by lengthening the flow paths of water within the dam and its foundations. The flow path can be increased by extending the impermeable upstream blankets. Hence it was proposed to extend the impermeable upstream blanket also in order to avoid piping which is usually develops many years after construction. Further, the surplus escape was also repaired. Details of the well connected to the barrel outlet is shown in Fig. 1.

Fig. 1 : Details of well connected to the outlet

Thus, the seepage was tried to arrest by checking and arresting components of the dam one by one and it was noticed that the barrel is the source of the seepage. So, a repair work was arranged to repair the barrel. As the random rubble masonry barrel is very narrow of the order of 0.9 m wide by 1.5 m deep, it was not possible to enter in to this and repair the barrel 84 m length. The sluice is provided with a vertical well with inner dia 1.60m at top and 1.20m at bottom. Finally, repair of this sluice with an innovative technology, similar through a push technology of steel barrel in to this RCC barrel with railings at the bottom and grouted the space between the outside of the RR masonry and the outer side the steel casing caused the stoppage of leakage. Thus, for the first time since 1980, the dam has been opened on 21st August 2019 at 12.54 M water level. The dam in Thekkumkara Grama Panchayath has regained its lost pride by the leak-proof renovation works . Details of this work is provided in this paper with analysis.

2. SALIENT FEATURES OF THE DAM

Salient features of the dam are given below.

1.	Length of the Reservoir	- 143.00 meter
2.	Height of the Reservoir	- 18.30
3.	River basin	- Puzhakkal river, Thrissur District, Kerala, India.
4.	Volume content of dam	- 1.58 Mm^3
5.	Gross storage capacity	- 1.58Mm^3
6.	Reservoir area	- 1.53sqkm
7.	Spillway capacity	- 4 vents 2.28 x1.525 m
8.	Maximum Water level	- +129.235 meter
9.	Reservoir bottom width	- 84.00 meter
10.	Top level	- +131.06 meter
11.	Bottom level	- +113.00 meter
12.	River sluice (Barrel) level	- +115.00 meter
13.	Sluice Valve Well dia	- 1.20 meter
14.	Sluice well location	- 37.00 M from up toe
15.	Sluice Barrel size	- 0.60x1.5/1.2 meter
16.	Barrel bed	- Concrete
17.	Barell side wall	- Stainless steel casing
18.	Barell top	- Pre-cast RCC slab
19.	Latitude	- 10°37’09.8”N
20.	Longitude	- 76°14’12.1”E

3. PROBLEMS ASSOCIATED WITH RANDOM MASONRY BARREL WITH PRECAST CONCRETE TOP SLABS

The RR masonry barrel is in a dilapidated condition due to number of cavities and pot holes have been developed and the voids created through these openings in the barrel. Well sluice and joints between masonry walls and precast roof concrete slabs of barrel resulted severe seepage of water through the barrel and this flow of water is mainly due to seepage water through body of dam. The masonry structure of the barrel is found dislocated and sunken condition due to settlement. Cover slabs also moved from its original location. Slush and water convey out from these weak portions to the barrel. During construction of barrel a lot of weep holes have been provided which guided to body leakage to the barrel with the progress of time. The displacement of cover slabs leads to cracks through the joint of masonry and slab bearings allowing entry of water from the body of dam. These cracks developed in sluice well and side walls also lead to heavy seepage entering in to the barrel. For the treatment and improvements/rectifications against the above weaker parameters , epoxy based repairing was not possible even though it provides high early strength, it will not bond in damp condition, and due to limited working space, proper mixing and application, supervision are difficult in the barrel.

Finally, a stainless steel lining works to ensure perfect water tightness and the same will withstand settlement up to a certain level was considered.

4. DETAILS OF STAINLESS STEEL BARREL PROPOSED TO BE PLACED INSIDE RR BARREL

The mouth of the existing RR barrel was widened to provide insertion of the proposed stainless steel barrel. A ring bund was also provided in the upstream side of the barrel to arrest entry of water in to the barrel. PVC pipes of diameter 7.5 cm to inject bentonite and earth slurry in to the dam body near the barrel. Non-shrink free flow grout was proposed to fill in the space between the outside of the SS barrel and inside of existing RR barrel. Apart from this, mechanical parts are scrutinized and corrected. A rail was initially laid on the bottom of this barrel and the stainless steel caging of size 0.9 m wide by 1.5 m deep was pushed from the downstream end to the upstream end. Each piece of the single barrel was 6 m long. After inserting the first piece, second piece was welded on the back of the first piece by butt welding. Further, the first and second parts of the barrel were pushed inside the body of the dam. Similarly, pushing was carried on until the barrel reached near the well. Proper connections were then set in for the hydro mechanical parts. Further, the above mentioned bentonite earth grouting on the body of the dam coupled with filling of non-shrink grout on the gap between the steel barrel and the RR outside of existing barrel was carried out to prevent lateral seepage along the outside surface of the steel barrel and the inner side of the RR barrel.

5. METHOD OF ANALYSIS

The analysis and design of the stainless-steel barrel has been carried out in two phases as given as following.

Structural component- Structural component is checked by modelling in STAADPRO considering it as a free body with the associated forces. For this purpose, the section with maximum overburden was chosen, which is 131.06- (115+1.5) = 14.56 m, with the length of 6 m, which is the length of a unit of the steel barrel.

Hydraulic component- SS Barrel was checked for the hydraulic parameters like check for piping effect, adequacy of creep length. Check also was made for the discharge in the new section to verify that the discharge requirement is met, as the old section is larger than the new section.

6. MODELLING OF THE STAINLESS-STEEL BARREL FOR SETTLEMENT AND STRENGTH

Considering the safe bearing capacity of soil as 150 kN/m^2 as per soil reports of similar soils, modulus of subgrade reaction can be found out as following.

Modulus of subgrade reaction $= 40 \times 3 \times 150$

$= 18000$ kN/m^3

Pressure distribution at top of barrel is assumed to have a triangular distribution of pressure as shown in fig. 2. Maximum pressure in the triangular distribution of pressure

$$= \frac{0.3}{\tan 60} \times 20$$

$= 3.46$ kN/m^2

Maximum pressure possible from overburden $= 14.56 \times 20$

$= 291.2$ kN/m^2

This will act as overburden pressure and will be constant for the 1.5 m height of barrel.

Total pressure at the top = 291.2 kN/m^2

Total pressure at the bottom = 291.2 +1.5 × 20 × 0.33 kN/m^2

= 301.1 kN/m^2

(Considering angle of internal friction as 30 degrees on the conservative side, ka= 0.333 and assuming that drainage are fully operational)

Overburden pressure and side pressure will be active when the earthen dam is wet insider, when the phreatic line is at the highest curve. So, the side active pressure is considered conservatively as following.

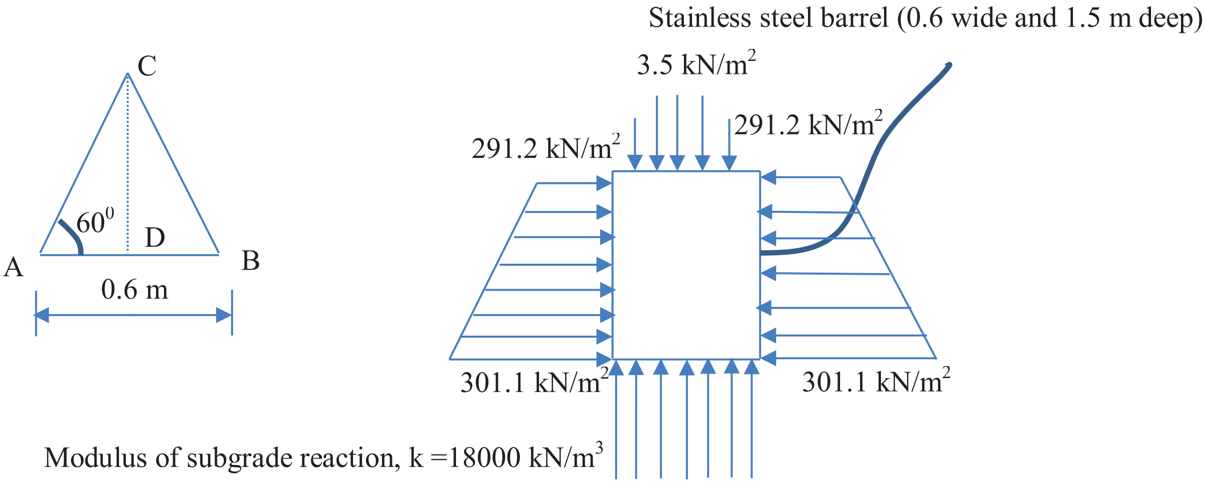

Fig. 2 : Stainless steel barrel with forces

Consider one metre length of the barrel for modelling in STAADPRO, the details of model and results are given in Fig. 3 below.

Results show that all members pass in the design check and the plate thickness of 6 mm is found to be sufficient.

From the above deliberations, it is clear that the barrel pushing through rails are safe against the given loads. Stresses in the material as per STAADPRO are also within safe limits as per stress contour in Fig. 4.

Now, it is required to check the barrel for hydraulic aspects.

Detailed STAAD input programme is given in Annexure-1.

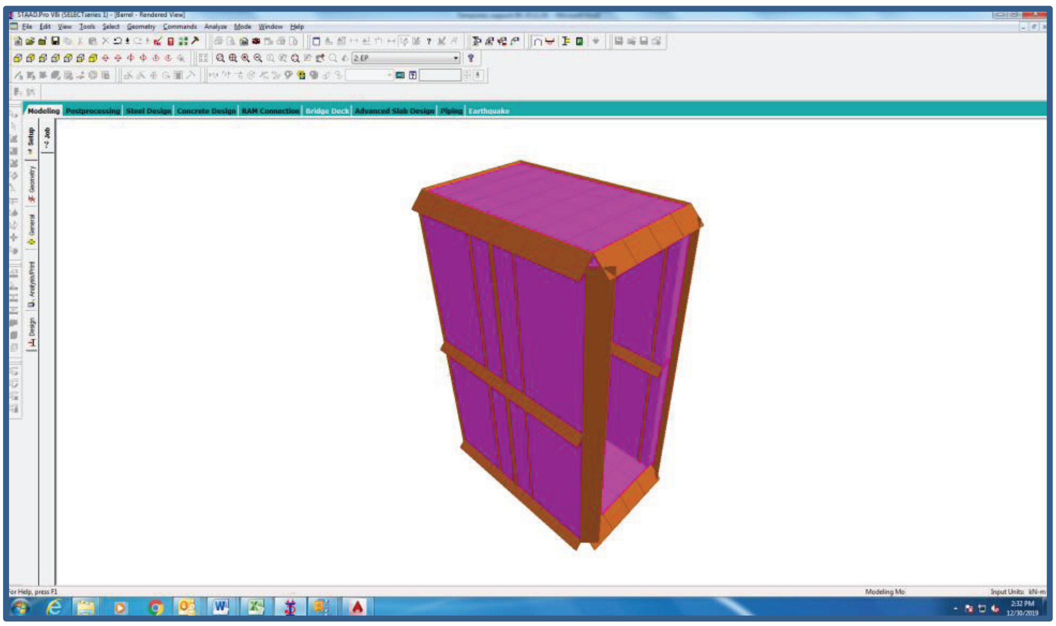

Fig. 3 : 3 D view of the model of barrel

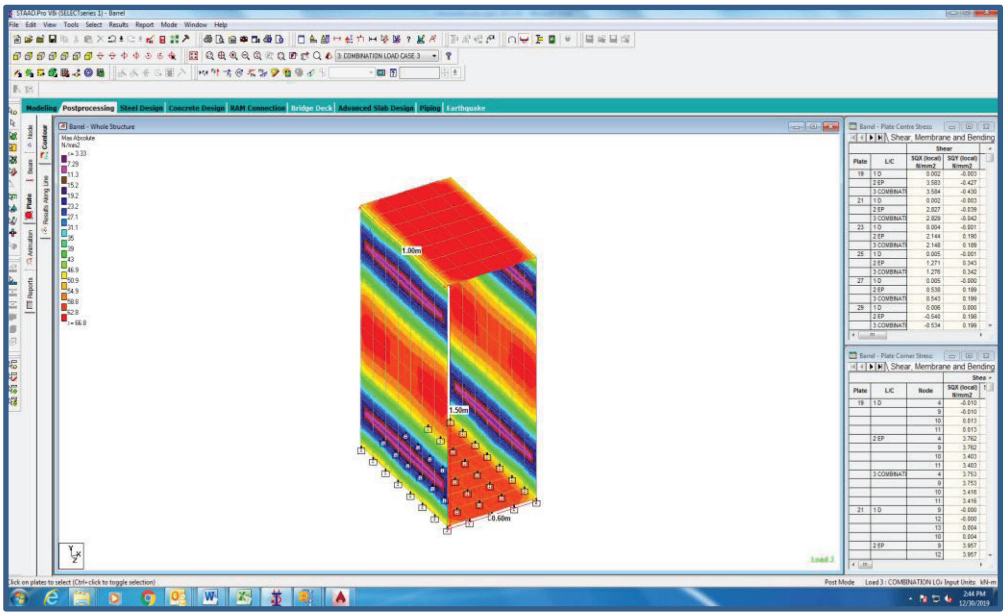

Fig. 4 : Stress contour in the stainless steel showing within limits

7. CHECK FOR PIPING

Consider Bligh's creep coefficient for soil as 5, as the soil is considered as silt and sandy clay.

$$L = CH \quad \text{...(1)}$$

Where 'L' is the creep length and 'H' is the head loss.

For a head loss of 14.56 m (at the level of the barrel), creep length required for safely passing out water = 14.56×5 = 72.8 m (C=5, as per the soil condition at site). This is less than reservoir bottom width of 84 m, and hence, there is no threat to piping.

As Bligh's creep theory is related to Darcy's law, limitations of Darcy's law are also applicable here. These limitations are (a) The size of soil particles shall not be more than 2 mm and (b) Velocity of flow through the porous medium shall be less than 5 mm/s.

8. CHECK FOR DISCHARGE THROUGH BARREL

Ayacut area for the dam is 150.70 Ha. Considering a duty of 60 acres per cusec (857.2 Ha/cu.m) (Department manual), discharge required = 150.7/857.2 = 0.18 m^3/s.

Maximum discharge through the barrel shall be calculated as following.

As per CWC norms on Piped Irrigation Network (PIN), permissible velocity through channel

$$= 1/N \times R^{2/3} \times S^{1/2} \quad \text{....(2)}$$

$$N = 0.011$$

R= Ratio of wetted area to wetted perimeter

$$= 1 \times 0.6/2.6$$

$$= 0.23$$

S is the slope, which is 1 in 1000.

$$\text{Hence, velocity, } V = 1/0.011 \times (0.23)^{2/3} \times (1/1000)^{1/2}$$

$$= 1.08 \text{ m/s}$$

$$\text{Discharge, } Q = V \times A \quad \text{...(3)}$$

$$= 1.08 \times 1 = 1.08 \text{ m}^3/\text{s}$$

This is more than the required velocity of 0.18 m^3/s and hence, the channel is deemed to satisfy the discharge requirements.

9. CONCLUSIONS

Above innovative design and application of stainless steel barrel was successful to prevent excessive seepage through dams and the reservoir was in full operation after a decade of seepage issues. Post analysis scenario was also considered and the system was found to be satisfactory.

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ANNEXURE-1- STAAD input programme on barrel analysis and design

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STAAD SPACE
START JOB INFORMATION
ENGINEER DATE 30-Dec-19
END JOB INFORMATION
INPUT WIDTH 79
UNIT METER KN
JOINT COORDINATES
1 0 1.5 0; 2 0.6 1.5 0; 3 0.6 0 0; 4 0 0 0; 5 0 1.5 1; 6 0.6 1.5 1;
7 0.6 0 1; 8 0 0 1; 9 0 0.15 0; 10 0 0.15 0.142857; 11 0 0 0.142857;
12 0 0.3 0; 13 0 0.3 0.142857; 14 0 0.45 0; 15 0 0.45 0.142857;
16 0 0.6 0; 17 0 0.6 0.142857; 18 0 0.75 0; 19 0 0.75 0.142857;
20 0 0.9 0; 21 0 0.9 0.142857; 22 0 1.05 0; 23 0 1.05 0.142857;
24 0 1.2 0; 25 0 1.2 0.142857; 26 0 1.35 0; 27 0 1.35 0.142857;
28 0 1.5 0.142857; 29 0 0.15 0.285714; 30 0 0 0.285714;
31 0 0.3 0.285714; 32 0 0.45 0.285714; 33 0 0.6 0.285714;
34 0 0.75 0.285714; 35 0 0.9 0.285714; 36 0 1.05 0.285714;
37 0 1.2 0.285714; 38 0 1.35 0.285714; 39 0 1.5 0.285714;
40 0 0.15 0.428571; 41 0 0 0.428571; 42 0 0.3 0.428571;
43 0 0.45 0.428571; 44 0 0.6 0.428571; 45 0 0.75 0.428571;
46 0 0.9 0.428571; 47 0 1.05 0.428571; 48 0 1.2 0.428571;
49 0 1.35 0.428571; 50 0 1.5 0.428571; 51 0 0.15 0.571429;
52 0 0 0.571429; 53 0 0.3 0.571429; 54 0 0.45 0.571429;
55 0 0.6 0.571429; 56 0 0.75 0.571429; 57 0 0.9 0.571429;
58 0 1.05 0.571429; 59 0 1.2 0.571429; 60 0 1.35 0.571429;
61 0 1.5 0.571429; 62 0 0.15 0.714286; 63 0 0 0.714286;
64 0 0.3 0.714286; 65 0 0.45 0.714286; 66 0 0.6 0.714286;
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79 0 0.9 0.857143; 80 0 1.05 0.857143; 81 0 1.2 0.857143;
82 0 1.35 0.857143; 83 0 1.5 0.857143; 84 0 0.15 1; 85 0 0.3 1;
86 0 0.45 1; 87 0 0.6 1; 88 0 0.75 1; 89 0 0.9 1; 90 0 1.05 1;
91 0 1.2 1; 92 0 1.35 1; 93 0.6 1.5 0.142857; 94 0.6 1.35 0.142857;
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230 184 185 188 187; 231 185 96 98 188; 232 50 186 189 61;
233 186 187 190 189; 234 187 188 191 190; 235 188 98 100 191;
236 61 189 192 72; 237 189 190 193 192; 238 190 191 194 193;
239 191 100 102 194; 240 72 192 195 83; 241 192 193 196 195;
242 193 194 197 196; 243 194 102 104 197; 245 83 195 198 5;
247 195 196 199 198; 249 196 197 200 199; 250 197 104 6 200;
252 4 201 202 11; 254 201 203 204 202; 256 203 205 206 204;
257 205 3 171 206; 258 11 202 207 30; 259 202 204 208 207;
260 204 206 209 208; 261 206 171 172 209; 262 30 207 210 41;
263 207 208 211 210; 264 208 209 212 211; 265 209 172 173 212;
266 41 210 213 52; 267 210 211 214 213; 268 211 212 215 214;
269 212 173 174 215; 270 52 213 216 63; 271 213 214 217 216;
272 214 215 218 217; 273 215 174 175 218; 274 63 216 219 74;
275 216 217 220 219; 276 217 218 221 220; 277 218 175 176 221;
279 74 219 222 8; 281 219 220 223 222; 283 220 221 224 223;
284 221 176 7 224;
ELEMENT PROPERTY
19 21 23 25 27 29 31 33 35 37 39 TO 47 49 51 TO 59 61 63 TO 71 73 75 -
76 TO 83 85 87 TO 95 97 99 101 103 105 107 109 111 113 115 116 119 -
121 123 125 127 129 131 133 TO 138 140 142 TO 147 149 151 TO 156 158 -
160 TO 165 167 169 TO 174 176 178 TO 183 185 187 TO 192 194 -
196 TO 201 203 205 207 209 211 213 215 216 218 220 222 TO 243 245 -
247 249 250 252 254 256 TO 277 279 281 283 284 THICKNESS 0.06
DEFINE MATERIAL START
ISOTROPIC STAINLESSSTEEL
E 1.9793e+008
POISSON 0.3
DENSITY 76.8195
ALPHA 1.8e-005
DAMP 0.03
ISOTROPIC STEEL
E 2.05e+008

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POISSON 0.3
DENSITY 76.8195
ALPHA 1.2e-005
DAMP 0.03
END DEFINE MATERIAL
MEMBER PROPERTY INDIAN
1 TO 12 17 18 20 22 24 26 28 30 32 34 36 38 48 50 60 62 72 74 84 86 -
96 98 100 102 104 106 108 110 112 114 117 118 120 122 124 126 128 -
130 132 139 141 148 150 157 159 166 168 175 177 184 186 193 195 202 -
204 206 208 210 212 214 217 219 221 244 246 248 251 253 255 278 280 -
282 287 TO 300 303 TO 342 TABLE ST ISA100x100x7
CONSTANTS
MATERIAL STAINLESSSTEEL MEMB 19 21 23 25 27 29 31 33 35 37 39 TO 47 -
49 51 TO 59 61 63 TO 71 73 75 TO 83 85 87 TO 95 97 99 101 103 105 -
107 109 111 113 115 116 119 121 123 125 127 129 131 133 TO 138 140 -
142 TO 147 149 151 TO 156 158 160 TO 165 167 169 TO 174 176 -
178 TO 183 185 187 TO 192 194 196 TO 201 203 205 207 209 211 213 215 -
216 218 220 222 TO 243 245 247 249 250 252 254 256 TO 277 279 281 -
283 284
MATERIAL STEEL MEMB 1 TO 12 17 18 20 22 24 26 28 30 32 34 36 38 48 -
50 60 62 72 74 84 86 96 98 100 102 104 106 108 110 112 114 117 118 -
120 122 124 126 128 130 132 139 141 148 150 157 159 166 168 175 177 -
184 186 193 195 202 204 206 208 210 212 214 217 219 221 244 246 248 -
251 253 255 278 280 282 287 TO 300 303 TO 342
SUPPORTS
252 254 256 TO 277 279 281 283 -
284 PLATE MAT DIRECT Y SUBGRADE 18000 PRINT
LOAD 1 LOADTYPE Dead  TITLE D
SELFWEIGHT Y -1 LIST 1 TO 12 17 TO 284 287 TO 300 303 TO 342
LOAD 2 LOADTYPE Live REDUCIBLE TITLE EP
ELEMENT LOAD
19 39 51 63 75 87 99 PR GX 301
37 49 61 73 85 97 116 PR GX 291.2
35 47 59 71 83 95 115 PR GX 293.7
33 46 58 70 82 94 113 PR GX 294.9
31 45 57 69 81 93 111 PR GX 296.1
29 44 56 68 80 92 109 PR GX 297.3
27 43 55 67 79 91 107 PR GX 298.6
25 42 54 66 78 90 105 PR GX 299.8
23 41 53 65 77 89 103 PR GX 301.2
21 40 52 64 76 88 101 PR GX 300.5
205 207 209 211 213 215 216 PR GX -301
196 TO 201 203 PR GX -300.5
187 TO 192 194 PR -299.8
178 TO 183 185 PR GX -298.6
```

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169 TO 174 176 PR GX -297.3
160 TO 165 167 PR GX -296.1
151 TO 156 158 PR GX -294.8
142 TO 147 149 PR GX -293.7
133 TO 138 140 PR GX -291.2
119 121 123 125 127 129 131 PR GX -291.2
220 222 225 226 229 230 233 234 237 238 241 242 247 249 PR GY -3.5
218 223 224 227 228 231 232 235 236 239 240 243 245 250 PR GY -1
LOAD COMB 3 COMBINATION LOAD CASE 3
1 1.0 2 1.0
PERFORM ANALYSIS PRINT STATICS CHECK
PARAMETER 1
CODE BS5950
CHECK CODE ALL
FINISH
```