INVENTING UNIQUE BRIDGE ABUTMENTS IN UTTARAKHAND

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ABSTRACT

Though traditional bridge abutments are still in common use, an effort has been made to add exceptional features to bridge abutments while going for new bridges on rural roads in the state of Uttarakhand, India. While doing so, some of the key concerns were to achieve economy, improve performance during seismic conditions, reduce bulkiness of traditional abutments, minimize consumption of natural resources and add a little bit of elegance to the scenic hilly surroundings.

Comparisons were made among common type of stone masonry/PCC and RCC abutments while exploring possible ways of achieving the desired features. While proposing the abutment type, attention was also paid to the simplicity of construction as most of the bridges are going to be constructed at remote places.

Based on the exhaustive studies done and comparisons made it was found that U-type abutments with curved shaft (stem) are one which inherit the desired features. The curved abutment shafts behaved like a shell (arch) structure where stress flow predominantly become axial. This helped in achieving least possible thickness of abutment shaft and that also with nominal steel at many places. Reduction in bulkiness of the abutment shaft resulted not only into direct saving but also indirect savings due to reduced seismic forces acting over the abutment. In order to ensure correctness of the design forces, space frame grillage models were made wherever needed.

The paper primarily discusses about the features and design of U-type abutments with curved shafts along with their comparison with other type of commonly used abutments.

KEYWORDS:
Abutment, aesthetics, curved shaft, design, economy, performance, straight shaft

1. INTRODUCTION

Abutments are one of the key components of a bridge which are required at each end of the bridge to support the bridge superstructure and also to retain the earth fill of the approach embankment/road. In case of small bridges, cost of the bridge abutments is significant as compared to the overall cost of the bridge. The ratio of abutment cost to overall bridge cost reduces with bridge length as abutments are required only at each end of the bridge i.e. longer is the bridge length, lesser is cost component of bridge abutments. In hilly areas generally bridge length is small i.e. upto about 50-75m and that is why cost of the bridge abutments have significant impact on overall cost of the bridge.

An initiative has therefore been taken in the state of Uttarakhand to optimize cost and to enhance the performance of bridge abutments specifically in stringent seismic conditions. While exploring the solutions, attention was also paid to minimize the consumption of natural resources, which is one of the key worries across the globe in the process of development.

Bridges are traditionally provided with massive stone masonry/PCC type abutments or RCC U-type/counterfort type/box type/spill through type abutments. With due considerations given to the ease of construction and expertise available at the remote places, various alternatives were explored and it was found that providing U-type abutments with curved shaft (stem) (Figure 1 & 2) is the most suited one for the proposed bridges.

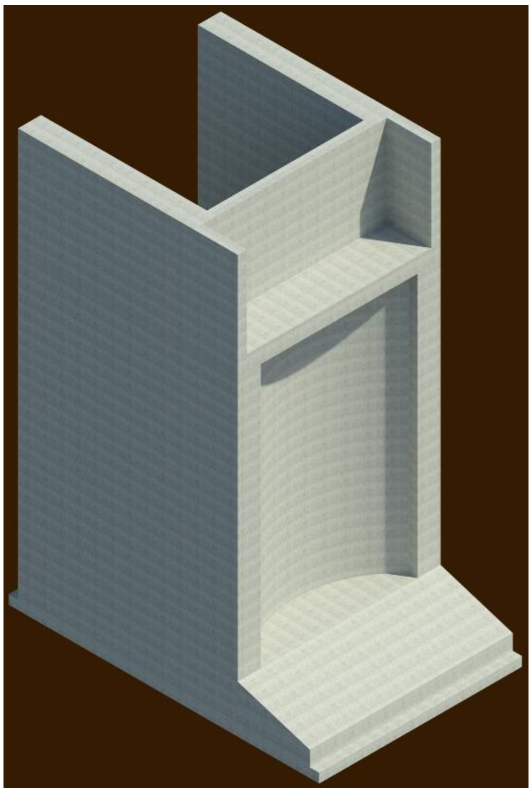

FIGURE 1 Abutment with curved shaft

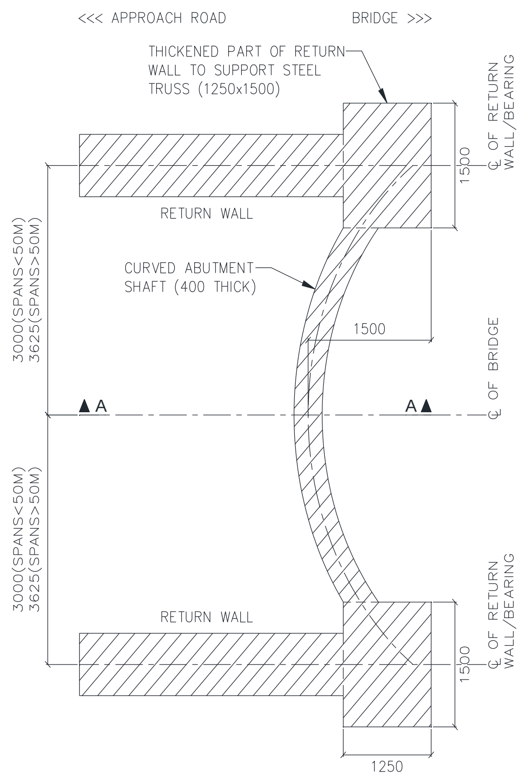

FIGURE 2(a) Plan at abutment base

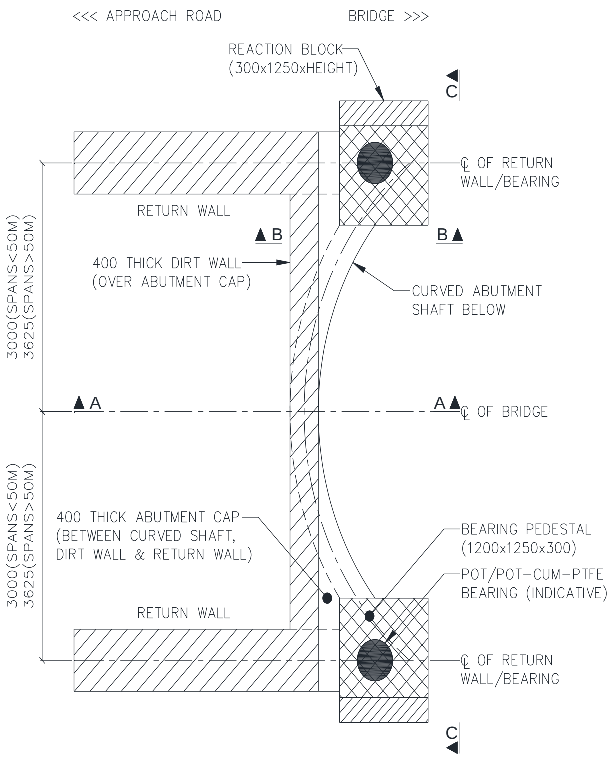

FIGURE 2(b) Plan at abutment cap

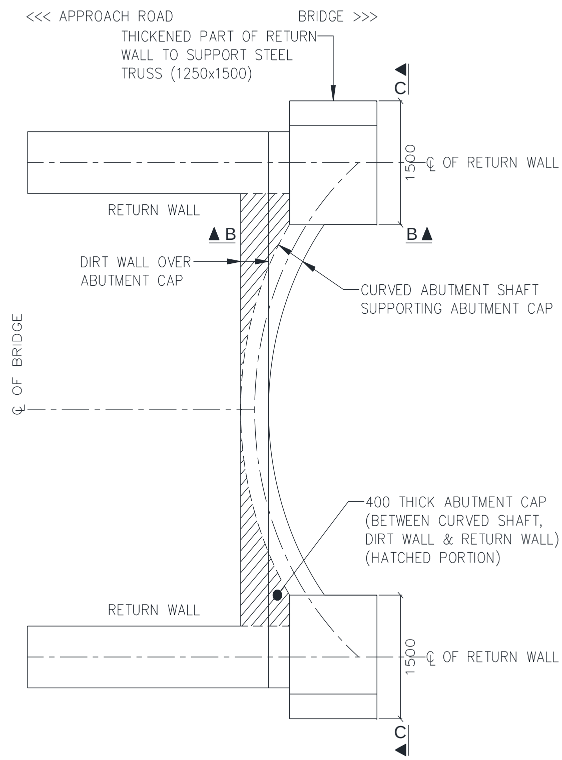

FIGURE 2(c) Extent of abutment cap

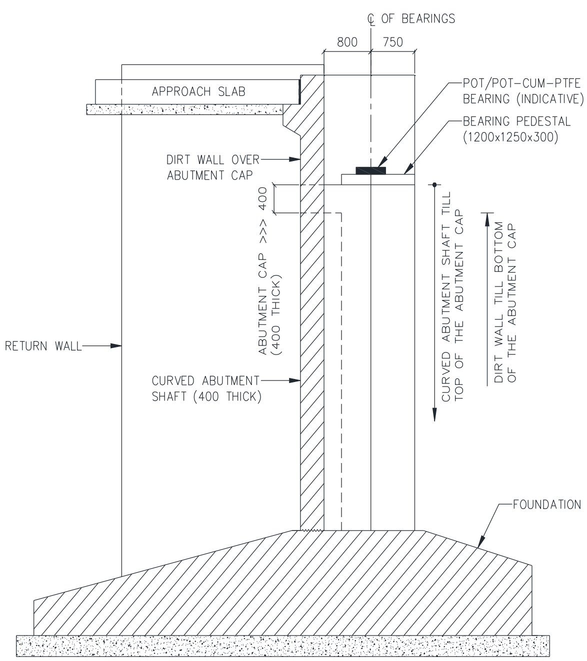

FIGURE 2(d) Section A-A of abutment

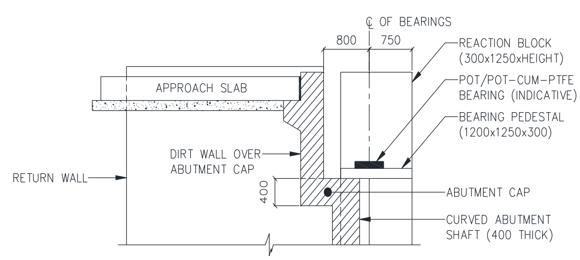

FIGURE 2(e) Section B-B of abutment

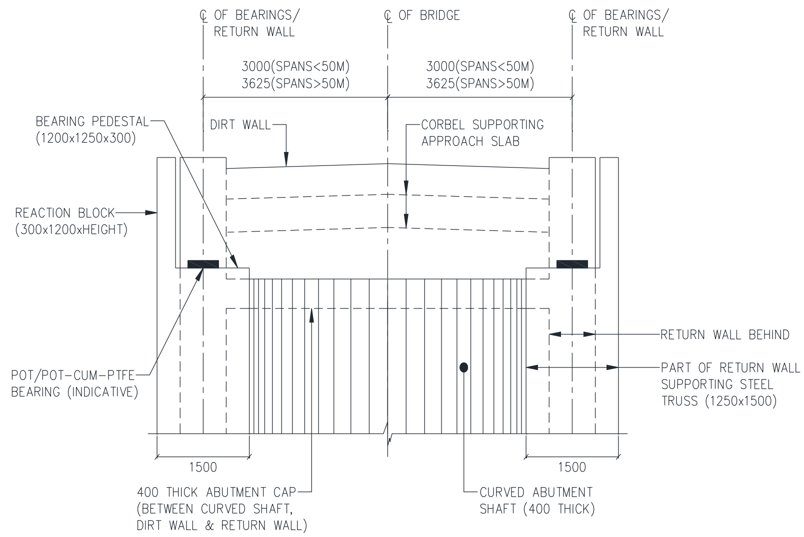

FIGURE 2(f) Elevation C-C of abutment

Comparisons were made among various type of abutments i.e. stone masonry/PCC abutments (gravity type) and RCC abutments (U-type, counterfort type, box type and spill through type) while thinking about the possible ways of enhancing desired features of the bridge abutments. In order to ensure correctness of the design forces, space frame grillage models were prepared wherever needed.

Due to small carriageway widths (4.25m & 5.50m) and steel truss (through/semi through) type superstructure, it was feasible to align the return walls along center line of trusses which helped in supporting the bearings directly over return walls (thickened part in the front, Figure 2) and therefore minimizing the size of abutment caps (Figure 2) to a great extent. In this process, abutment shaft simply acted like an earth retaining structure and could be made free from the loads transferred from the superstructure. The proposed abutments with unparalleled features are going to be constructed first time in the world.

2. INITIAL COMPARISONS

Initial comparisons were made among various type of abutments before going for exhaustive studies so that efforts could be minimized and work could be completed in stipulated time schedule.

2.1 Stone Masonry & PCC Abutments:

Though such abutments (Figure 3) are relatively simple to construct as compared to RCC abutments and utilize use of locally available materials, they are generally quite bulky, stiff and brittle resulting into more consumption of natural resources. Due to bulkiness, stiffness (i.e. low time period) and brittleness, they are subjected to relatively high seismic forces resulting into highly uneconomical design under stringent seismic conditions. They are, therefore, generally not recommended in high seismic zones. Latest IRC provisions restrict use of such abutments in moderate seismic zones i.e. zones II & III only. However, in order to have an idea about cost of such abutments, these were designed based on old codal provisions (permitting use of such abutments in high seismic zones i.e. zone IV & V) and cost of such abutments were found considerably high as compared to RCC abutments. It was also noticed that when designed for high seismic forces (zone IV & V as per old provisions), the foundation sizes became so bulky that, sometimes, they could not be accommodated in the available space which is generally restricted in hills.

2.2 RCC U-Type Abutments:

These are perhaps most commonly used abutments across the globe where relatively thick straight abutment shaft (stem) is provided to support the bridge superstructure and also to retain the earth behind (Figure 4). As discussed in the paper, these abutments were finally selected and modified to enhance the features by replacing thick straight abutment shaft by thin curved shaft.

FIGURE 3 Stone masonry abutment

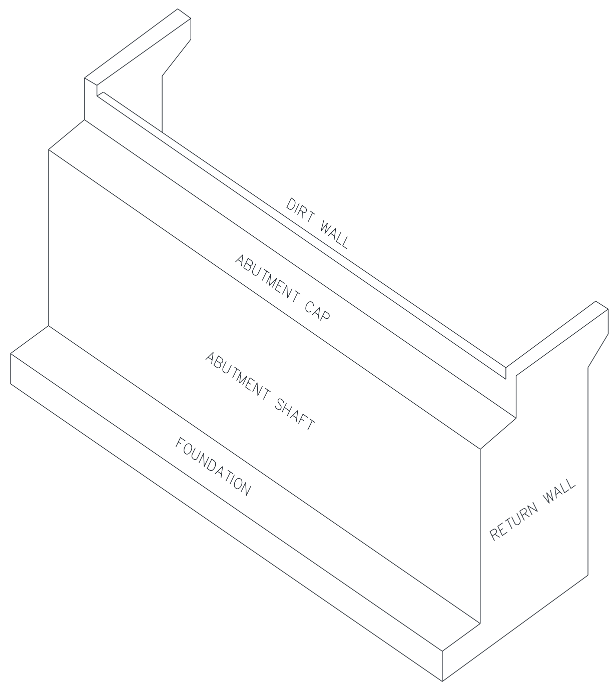

FIGURE 4 U-type RCC abutment

2.3 RCC Counterfort Type Abutments:

These are similar to U-type abutments with intermediate counterforts (Figure 5) to reduce thickness of the abutment shaft. Such abutments are generally suitable in case of wide and tall abutments where intermediate counterforts help in reducing span and hence thickness of the abutment shaft. Such abutments could not be selected because of relatively narrow deck widths (4.25m & 5.50m carriageway widths) where provision of counterforts could not produce desired economy. Furthermore, stiffness of counterfort type abutments is generally high as compared to U-type abutments resulting into increased seismic forces and earth pressure under seismic conditions.

FIGURE 5 Counterfort type abutment

2.4 RCC Box Type Abutments

Such abutments (Figure 6) are generally preferred where weight of backfilled soil (resting over the foundation) is to be avoided or reduced to have base pressure within the allowable limits. Such abutments are generally suitable in case of very tall abutments or where bearing capacity of sub-surface soil is low. Stiffness of box type abutments is also generally high as compared to U-type and counterfort type abutments resulting into increased seismic forces and earth pressure under seismic conditions. Such abutments also could not produce desired economy and that is why not selected for the proposed bridges.

FIGURE 6 Box type abutment

2.5 RCC Spill Through Type Abutments:

Such abutments (Figure 7), where backfilled soil is allowed to spill through the space between the columns, are generally not preferred as their performance largely depends upon the stability of the slope of the soil spilling through the space between columns (Figure 8).

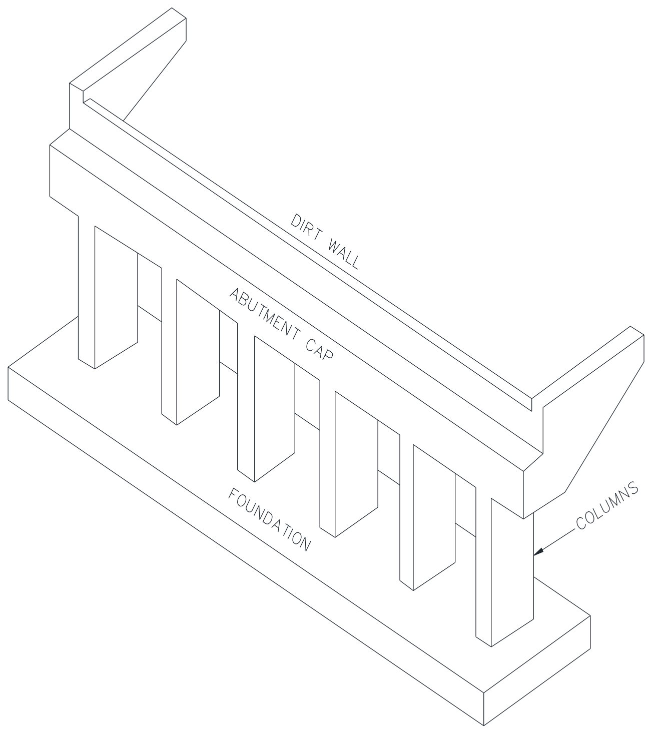

FIGURE 7 Spill through type abutment

FIGURE 8 Failure of slope of spilling soil

3. DETAILED STUDY

Based on the initial comparisons made, it was finally decided to go for U-type abutment with curved abutment shaft. In order to have precise results space frame grillage models were prepared for different heights (4m, 6m, 8m, 10m, 12m & 14m above foundation top) of U-type abutment with curved and straight shafts (Figure 9 & 10).

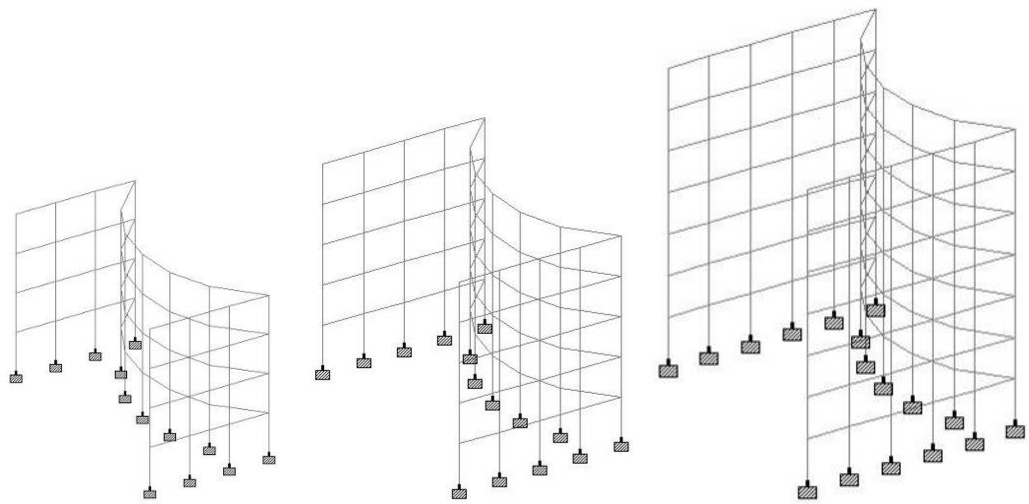

FIGURE 9(a) Structural model with curved shaft (4, 6 & 8m high abutments)

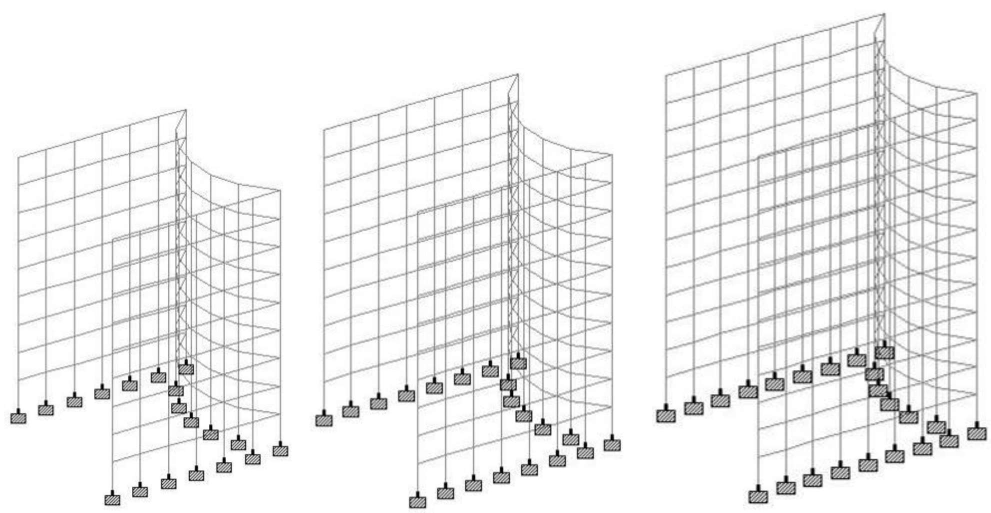

FIGURE 9(b) Structural model with curved shaft (10, 12 & 14m high abutments)

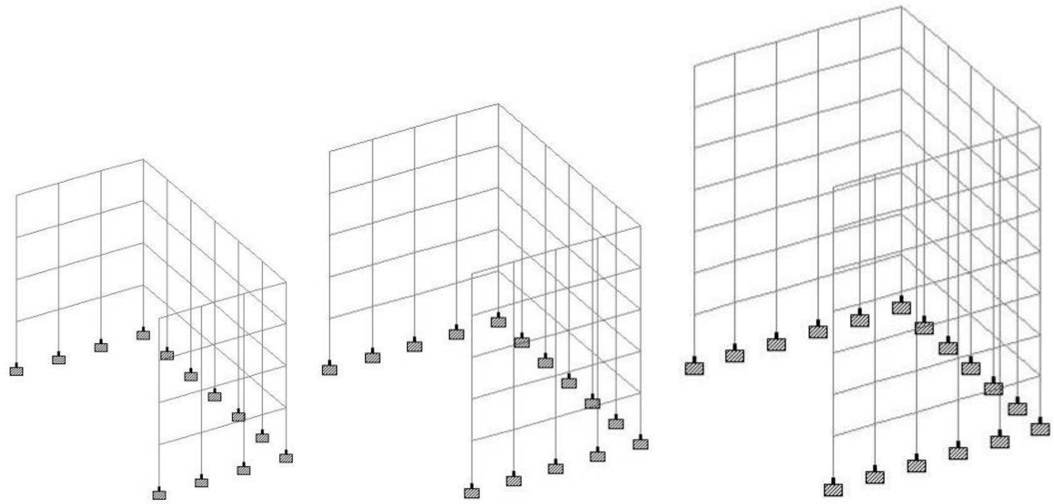

FIGURE 10(a) Structural model with straight shaft (4, 6 & 8m high abutments)

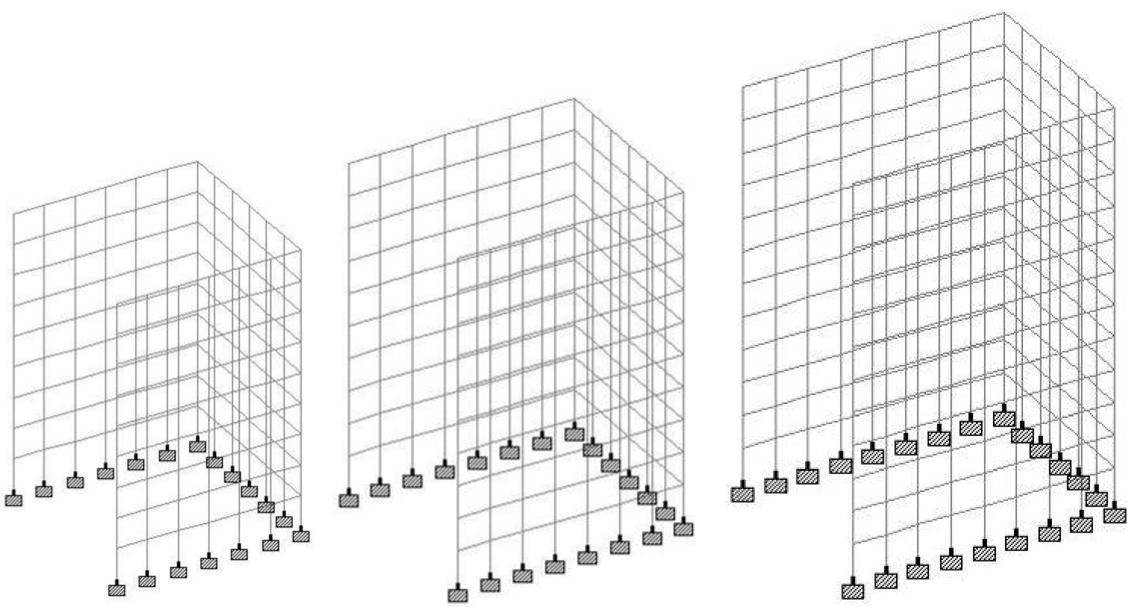

FIGURE 10(b) Structural model with straight shaft (10, 12 & 14m high abutments)

4. COMPARISON OF RESULTS

Results obtained from above mentioned structural models are summarized below. The height of abutment mentioned in the tables are with respect to top of the foundation. For the purpose of simplicity of understanding the behavior, bending moments and shear forces given in the following tables are corresponding to active earth pressure ($K_a = 0.30$) & lateral pressure due to live load surcharge (2.4 t/m^2) acting on the abutment shaft. This is because design of abutment shaft is primarily governed by lateral earth pressure and loads transferred from bridge superstructure have very nominal impact on the design.

TABLE 1 Bending Moments & Shear Forces for 4m High Abutment

Abutment Type	Maximum moment in vertical member	Maximum shear in vertical member	Maximum moment in horizontal member	Maximum shear in horizontal member
Curved Shaft	2.72 t-m/m	4.86 t/m	0.87 t-m/m	0.86 t/m
Straight Shaft	3.91 t-m/m	5.45 t/m	2.49 t-m/m	2.81 t/m
Ratio(Curved/Straight)	0.70	0.89	0.35	0.31

TABLE 2 Bending Moments & Shear Forces for 6m High Abutment

Abutment Type	Maximum moment in vertical member	Maximum shear in vertical member	Maximum moment in horizontal member	Maximum shear in horizontal member
Curved Shaft	3.54 t-m/m	6.37 t/m	1.43 t-m/m	1.33 t/m
Straight Shaft	4.97 t-m/m	6.98 t/m	3.26 t-m/m	3.68 t/m
Ratio(Curved/Straight)	0.71	0.91	0.44	0.36

TABLE 3 Bending Moments & Shear Forces for 8m High Abutment

Abutment Type	Maximum moment in vertical member	Maximum shear in vertical member	Maximum moment in horizontal member	Maximum shear in horizontal member
Curved Shaft	5.59 t-m/m	9.63 t/m	2.80 t-m/m	2.41 t/m
Straight Shaft	7.50 t-m/m	10.06 t/m	5.26 t-m/m	5.80 t/m
Ratio(Curved/Straight)	0.75	0.96	0.53	0.42

TABLE 4 Bending Moments & Shear Forces for 10m High Abutment

Abutment Type	Maximum moment in vertical member	Maximum shear in vertical member	Maximum moment in horizontal member	Maximum shear in horizontal member
Curved Shaft	7.71 t-m/m	13.01 t/m	3.98 t-m/m	3.41 t/m
Straight Shaft	10.14 t-m/m	13.20 t/m	7.69 t-m/m	8.52 t/m
Ratio(Curved/Straight)	0.76	0.99	0.52	0.40

TABLE 5 Bending Moments & Shear Forces for 12m High Abutment

Abutment Type	Maximum moment in vertical member	Maximum shear in vertical member	Maximum moment in horizontal member	Maximum shear in horizontal member
Curved Shaft	8.74 t-m/m	14.60 t/m	4.67 t-m/m	4.13 t/m
Straight Shaft	11.42 t-m/m	14.76 t/m	9.01 t-m/m	9.93 t/m
Ratio(Curved/Straight)	0.77	0.99	0.52	0.42

TABLE 6 Bending Moments & Shear Forces for 14m High Abutment

Abutment Type	Maximum moment in vertical member	Maximum shear in vertical member	Maximum moment in horizontal member	Maximum shear in horizontal member
Curved Shaft	11.01 t-m/m	18.15 t/m	6.17 t-m/m	5.54 t/m
Straight Shaft	14.12 t-m/m	17.93 t/m	11.62 t-m/m	12.73 t/m
Ratio(Curved/Straight)	0.78	1.01	0.53	0.44

From the above tables, it can be seen that reduction in bending moments and shear forces of vertical members of curved shaft is about 22-30% & 0-11% respectively resulting into 22-30% saving in the vertical steel. Similarly reduction in bending moments and shear forces of horizontal members of curved shaft is about 47-65% & 56-69% respectively resulting into 47-65% saving in the horizontal steel & 56-69% saving in shear reinforcement (if required).

Furthermore, as discussed above, out of various abutment types, U-type abutments with curved shafts are relatively most flexible (high time period) resulting into better behavior under seismic conditions.

5. CONCLUSIONS

Abutments are one of the key components of a bridge and have significant impact on overall cost of the bridge specifically in the case of small bridges i.e. bridges upto 50-75m length. As most of the bridges in hilly states are small, an initiative was taken to optimize cost of the bridge abutments while proposing new bridges in the state of Uttarakhand. As discussed in the paper, a small change of making straight abutment shaft into curved shaft resulted into noticeable saving in the cost of the bridge. In the studies done, RCC U-type abutments with curved shaft were found about 15-30% cheaper as compared to various type of abutments in use. Also in case of wide and tall abutments, where provision of counterforts is beneficial, curved shafts may be provided between adjacent counterforts/return walls similar to that discussed in the paper which may help to achieve further economy of the proposal.