Study of Rockfall at Amritanjan Bridge Site on Mumbai – Pune Expressway – A Case Study

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ABSTRACT

Country's first Expressway Mumbai-Pune, which passes through the mountainous and rugged Deccan Trap province, suffers from major rockfall problems along this important transportation corridor. A significant number of accidents and casualties have been reported during 2003 and 2004 because of rockfalls and associated weathering processes. A reconnaissance inventory carried out by Central Road Research Institute (CRRI) revealed that about 90% of the slope failures along the stretch are due to rockfalls and rest 10% in the forms of debris falls, subsidence and sliding. The average daily traffic as on date on this expressway is nearly 15,000 PCU/day, generating a considerable amount of revenue. The existing rockfall problem, if not timely and appropriately addressed, may cause lot of damage to infrastructure and even may lead to loss of life and further hardships to the commuters. During investigation the team identified 17 sensitive locations, which were prone to rockfall/landslides. Investigations of all the identified areas have been carried out from various aspects which were thought crucial to slope stability such as geological, geomorphological and geotechnical. The extensive field and laboratory investigations were carried out to understand the most possible causes and the possible mechanism of the rockfalls. On the basis of these investigations, appropriate short term and long-term remedial measures were suggested for specific locations. This paper intends to present in brief about the field investigations, probable causes and remedial measures recommended to control the rockfall at one of the trouble location, Amritanjan Bridge site, on Mumbai – Pune expressway.

Keywords: Rockfall; Investigation; Stereographic projection; Remedial measures.

1. INTRODUCTION

Mumbai is the commercial capital of India and is growing significantly in size and population. So also Pune, the cultural capital of Maharashtra is growing into a major industrial and commercial centre. Hence, the importance of Mumbai - Pune road has increased tremendously in the last 8- 10 years. Due to the increase in the traffic on the existing National Highway and other link roads year after year are resulting in frequent jams, accidents and loss of travel time. About 400 persons were killed due to accidents on the existing Mumbai – Pune National Highway each year. This has made it necessary to build a new and independent expressway (Fig. 1). The expressway has reduced the travel time between the cities of Mumbai and Pune to approximately two hours. The expressway starts at Kalamboli (near Panvel) and ends at Dehu Road (near Pune), handles about 30,000PCU's, is designed for 1,00,000 PCUs. The expressway passes through the Sahyadri ranges with natural scenic beauty. Expressway has four-lane-wide tunnels at 5 locations namely Bhatan, Madap, Kamshet – I, Kamshet - II, Khandala and Aadoshi with total length of 6000 meters ((Fig. 1). There are separate tunnels for traffic in both the directions. The Expressway is opened for full length of 95 km from 1st March 2002. During 2003 and 2004 the expressway experienced the problem of rockfall. On the basis of the frequency of the recorded incidences of rockfall the critical areas have been identified. These critical areas of rockfall located at: Amritanjan Bridge, 14 km, 18km, 21.5km, 29.8km, 26.491km, 38.9km, 41km, 41.679km, 42.36km, 47.5km, 68km and 70 km. This paper discusses the field investigations carried out at one of the strategic location named as Amritanjan Bridge site, followed by most probable remedial measures for its prevention/protection.

2. ROCK SLOPE FAILURE IN AREA

Rockfalls occur by detachment of rock blocks from steeply dipping discontinuities along which little or no shear displacement takes place. The blocks then descend mainly through the air falling, bouncing, or rolling at rapid to extremely rapid speeds. When the slope is located along a roadway, rockfalls can enter traffic lanes, thereby causing accidents, delays, vehicle damage, injury, and even deaths.

The idealized, slope failure modes (Goodman and Kieffer, 2000) are (1) block sliding on a single face (some times termed slab sliding) (2) block sliding on two faces simultaneously along their lines of interaction (often termed wedge sliding) and (3) Overturning of multiple columns (Usually called toppling). Block and wedge failure modes are more common than toppling. Rockfall in general terms is used for the free fall of the rocks. However, depending upon the type and size of the material it can be defined in several ways like debris fall, soil fall, pebble fall etc. In the study area only rockfall and in a few places debris fall have been observed.

The rockfall in the area have been observed in the following situations.

(i) In the highly fractured and jointed basaltic rocks where intersecting joint surfaces separate the rock blocks or pieces. The separated rock pieces fall down depending upon the size of the separated mass.

(ii) It has also been noticed in the area that there is alternate of the layers of harder and softer strata. In such cases soft strata gets weathered and eroded while the harder strata hangs on. In due course of time the harder strata may go down in form of rockfall, boulder fall and debris fall.

(iii) Depending upon the conditions of the intersection of the joints, the rock may fail as a wedge and come down as a fall or wedge slide. In most of the cases in this area the failures are because of the wedge formation.

The different modes of failure in rock as highlighted by Goodman and Shi (1985) and Goodman and Keiffer (2000), are based on discontinuities, their interaction, or orientation with respect to the natural or the artificial slope (artificial refers to the slope produced out of excavation to create space for transportation routes, buildings etc.). The discontinuities intersect to form the finite blocks which move out, if oriented adversely, leaving behind a new space into which adjacent blocks can move. The sliding along an adversely oriented rock face will invariably occur if the kinematics conditions for such sliding are met, meaning that the direction of incipient motion daylights into the excavation. If the sliding surfaces do not daylight toppling, buckling, block slumping failures may occur.

3. CONDITIONS FOR ROCK FAILURE IN AREA

The area, as explained in preceding sections comprises basaltic rocks. The basaltic rocks are mainly of two varieties i.e. compact and amygdoidal. Besides, there is a layer of week material in between two varieties of basalt. These conditions are favorable for the erosion either by the surficial action or from internal erosion and piping. Both these types of erosion have been noticed in many of the problematic locations in the area. In many of the locations, it was observed that the week layer exists beneath rocks with open joints, which facilitates rapid erosion due to existing seepage, undermining the adjacent rocks resulting in rock failure. It has also been observed along the expressway cut slopes that the jointed / fractured rock mass is gradually loosened due to weathering and gravity under the process generally named as raveling (Goodman and Keiffer, 2000). The loosened rock mass frequently comes down on the expressway.

In many sections of the trouble sites, wedge failure due to interaction of non-parallel discontinuity surfaces has been noticed. Huge blocks of the detached rock masses fail from the slope and move or fall down to the expressway. The wedges formed due to intersection of the joints, not necessarily fail until they are met with the adverse conditions.

Toppling is another type of failure which has been observed in this area. Toppling failure involves rotation of column or blocks of rock about same fixed base and follows the simple geometrical conditions governing the toppling of a single block on an inclined surface (Hoek and Bray, 1981)

4. GEOLOGICAL STUDY ALONG EXPRESSWAY CORRIDOR

The area around the proposed expressway project represents a highly rugged and dissected terrain comprising western foothills and isolated spurs of the Western Ghats. The geological setting of the area is strikingly uniform consisting of sequence of Deccan Trap flow which is intruded by a number of basic intrusive. The basalts are capped by lateritic soil and are also covered by alluvium of limited thickness (2m to 10m) mainly confined to the banks of Patalganga and Panvel rivers and other tributaries (MSRDC, 1995). Except for some mineralogical and chemical variations, the basalts of the various lava flows are quite similar though they show some variations in the minor structural characters. The upper part of the flow is vesicular whereas the basal part is massive trap. Thus the thickness of the weathered mantle depends upon the exposure of the flow unit.

Basalts are fairly uniform in appearance and also in mineralogical and chemical compositions over wide areas. The lava flows can be broadly divided into massive and vesicular basalts. The massive basalt is generally greenish to dark grey in colour, hard and compact in nature, breaking with sub-conchoidal fracture. These fractured mass are more prone to failure under adverse slope condition. The vesicular basalts are amygdular or agglomeratic and at times brecciated in appearance are more prone to weathering and erosion. They become unstable where they are found in alternate layers. The massive basalt is again found in fine and coarse-grained varieties. Amgydules are rarely noticed in this variety of rock. The unconfined compressive strength of this variety of fresh and hard basalt rock varies from 400 kg/cm^2 (40MPa) to 2000 kg/cm^2 (200MPa) and specific gravity from 2.10 to 3.11.

The vesicular varieties can also be sub-divided into vesicular – amygdular variety and agglomeratic or brecciated variety. The amygdular varieties generally acquire a reddish shade after weathering. They are studded with innumerable rounded and oval shaped voids. If the vesicles are of uniform size and uniformly distributed, the rock is noticed to be more resistant and hard than the one, which lacks the uniformity in dimensions and distribution of the vesicles. The vesicles are usually filled up with dirty zeolities and calcities. The agglomeratic varieties are made up of angular and sub-rounded blocks and fragments of scoriaceous and amygdaloidal basalts imparting a rusty brown colour. The specific gravity and the unconfined compressive strength of these rocks vary from 0.236 to 0.244 and 29.2 MPa to 137.6 MPa respectively. Tuff breccias usually occurs near the top of flow and comprise angular to sub-angular fragments of dense basalt, vesicular basalt and red bole enclosed in the highly vesicular aphanatic matrix. The tuff breccias have extensive infillings of zeolite. These rocks are prone to weathering easily.

The bedrock along the alignment of the expressway comprising basalt is well exposed in the hill sections. At times, it is buried under thick cover of hill wash material comprising bouldary strata set in silty matrix on hill slopes. Basalt lava flows exposed along the proposed expressway alignment, crossing the Borghat and Bedsa caves hill form part of the extensive lava flows in western ghats. The hills through which the highway passes are drained by structurally controlled *nallahs*, major fracture planes and shears. The thickness of individual flow is reported to vary from 15m to as much as

300m and the contact of different flows is marked by presence of red bole bed, which is a highly vesicular zone with reddened top and break in slope. Each of the trappean flow has two distinguished units i.e. massive unit and vesicular unit. As the flow consists of several flow units, their geometry, top and bottom characteristics, joints and their attitude etc. vary from place to place. The massive basalts are very hard; fine to medium coarse intruded by dolerite dykes north of Panvel trending NW-SE, N-S, NNE-SSW and E-W directions. The massive basalt is well jointed. The vertical joints show the following dominant trends,

- N10E – S10W to N10W – S10E
- N25E – S25W to N40E – S40W
- N60E – S60W to N70E – S70W
- N70W – S70W to EW
- N35W – S35E to N45W – S45E

The vesicular trap units, which do not show any distinguished set of joints, are more prone to weathering and erosion.

5. STRUCTURE

The interpretation of the ERTS imageries of the west coast region by Geological Survey of India and Oil and Natural Gas commission has brought out the presence of numerous faults, fractures and dykes. Panvel flexure, which forms the only surface visible feature on the west coast, is known to be mildly seismogenic. The basement below this flexure is interpreted to be fractured and faulted as evinced by the presence of hot springs and occasional occurrences of mild earthquakes.

6. AMRITANJAN BRIDGE SITE

Amritanjan Bridge on the National Highway (towards Mumbai) goes across and above the expressway. There is a vertical rock outcrop/ ridge/sledge, which divide both the highways (Fig 2). The ridge extends for about 150m in length along expressway (left lane) as well as National Highway and about 10-40m in height along expressway and 5-20m along National Highway. The outcrop left after cutting is vertical up to 30m at the top of which there is a high tension transmission tower. The outcrop therefore, becomes significant in the following ways.

(i) Presence of transmission tower at the top of outcrop. The transmission tower is extremely important for the reason that it supplies power to a sizeable area of the region and its shifting is ruled out at least at the present time.
(ii) Expressway and National Highway run across its two sides.
(iii) Loosened rock blocks are falling from the vertical rock face.
(iv) There is high risk to the running traffic since there is hardly any space between the toe of the slope and the shoulder of the expressway.
(v) Expressway has to be free from the rockfall and every effort should be made to prevent the rock from falling down on the expressway.

Fig. 2 – A view of Amritanjan bridge rockfall site

Daylighting of the Problem

At this location, the major problem identified is of frequent fall of rock blocks from the vertical cut slope. The frequency of the rockfall increases during rainy season. The size of the blocks ranges from a few cm to 1.5 or 2.0m size. The impact of the falling rock as noticed is very high. There are instances of falling boulders damaging the side drains and the expressway. The slope is vertical and there is no object on which the detached rocks could hit so as to reduce their momentum before actually hitting the expressway. This direct fall of rock on expressway makes the impact more dangerous and could be some times fatal when they might hit a running vehicle.

Secondly, from the National highway, all surface water collected through side drain is drained out to the side slopes of expressway. There is no connecting drain, which could drain out the water without damaging the side slopes and the expressway. Since the water collected during rains is heavy, there is severe erosion of the side slope.

7. FIELD INVESTIGATIONS

The field investigations were focused on obtaining information about the condition of rock/soil, causes and mechanism of their failures etc. The rocks at this point, as in most of other areas, are in general two types of basalts, amygdaloidal and compact basalt. The compact basalt is fine grained and less weathered, but contrary to the amygdaloidal type it is more fractured. The fractures are more prominent at the intersection of the vertical discontinuities with the horizontal (base). At the top of the hill towards Mumbai (Fig. 3), the hillock has columnar joints at close spacing. The joints are open and provide easy access for entrance of huge quantity of water. These joints are presently in loose state (Fig. 4) and may experience toppling failure in the coming monsoon months due to ingress of water. The vesicular variety of basalt is more prone to weathering compared to the other variety; however, it is less jointed. The surficial weathering on the face of vesicular variety is more. There are predominantly three sets of joints i.e. the vertical, horizontal and oblique joints.

Fig. 3 – Columnar joints at top of the sledge

Fig. 4 – Close view of separated columnar joints

On the other hand, there are many other fractures, which are some time confused with the joints. The vertical joint sets daylight on the slope is part of the columnar joints assembly and most dominant joints with regular spacing. A few of the representative joints sets are plotted in a stereographic projection (Fig. 5). It is indicated from the stereographic projection of a few joints that there is a distinct interaction of joints forming wedges on the face of the slope towards both NW and also SW directions.

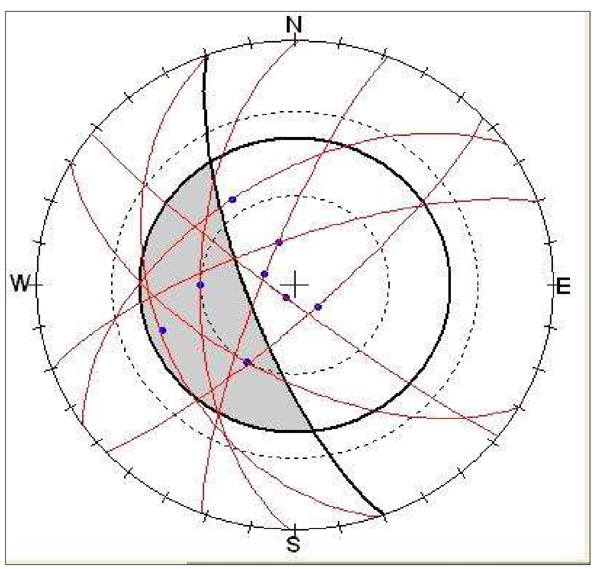

Fig. 5 – Stereographic projection indicating the wedges day lighting on the face of slope

There are some horizontal layers of week material, mainly, brownish in color, inter-bedded between the two basaltic layers. The week layer is also a product of the basaltic layer on which it rests. This layer has altered in the present form as a result of weathering (Fig. 6). This layer, being weathered and altered is extremely dangerous, if exposed because of its access to water. This layer can accelerate weathering and can facilitate further division between two basaltic layers, which finally can fail along its joints. The situation had already been day lighted on the face of the slope (Fig.7). After the construction of the highway there are few locations where the rock blocks are left in loose conditions. A few rock blocks seem to be tightly hanged, however, in due course of time due to water and gravity these blocks are expected to get loosened and fail in the form of rockfall.

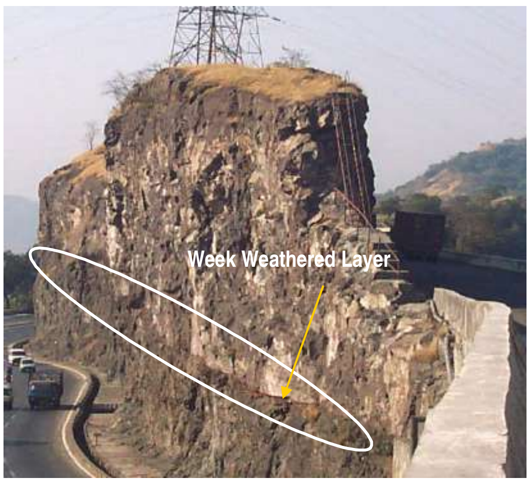

Fig. 6 – Weak pelagic clays and chert layer between the two successive flows

Fig. 7 – Weak layer sandwiched between two basaltic layers

Neither surface nor subsurface drains are presently provided at this location for water draining. Although at this location, the catchment is not big, however, the rainwater is enough to create troubles while infiltrating down into the slope through the joints at the top. The pore water pressures between the joints help in widening the existing joint openings and also wash the infillings in between the joints to make the joints free from cohesion as a separate block.

8. POSSIBLE REPERCUSSIONS IN CASE LEFT UNTREATED

- Loose blocks will keep on falling as they gets separated.
- Rock surface already exposed to weathering will accelerate the weathering process and will further aggravate the problem.
- The transmission tower at the top of the hill provides continuous vibration to the hill which in long term will further weaken the already weak bonding between the jointed rocks.
- Gradual deterioration may lead even to destabilization of transmission tower.
- This is a high-risk area as there is not much space left between the hill and the highway. Vehicles using the expressway are pass very close to the hill and any

stone falling from top of the hill may directly hit the vehicle with a very high impact.

9. REMEDIAL MEASURES

Number of methods are used today to prevent fall of rocks along roads such as trimming, rock bolts, shotcrete, and drainage. However it might be too expansive or too difficult to prevent all rocks from falling. If it is not so essential to prevent the rock from falling it may be appropriate to allow the rocks to fall but to prevent them from entering the roadway to reduce cost as well as risk. Jesse and Shakob (2005) studied the effectiveness of catchment ditches along Ohio roadways and evaluated 100 sites with the Oregon rockfall hazard rating system. Navaratnarajah et al. (2005) focuses on the analysis of global stability, anchor spacing, and support cable loads in wire mesh and cable net slope protection systems. They concentrated on the effect of mesh weight, the friction between mesh and rock surfaces and the accumulation of debris on the overall stability of the systems.

As discussed above, the site has jointed Basaltic rock of two kinds. Generally there are several fractures and few of the joint planes. The fine-grained massive basalt layers have high concentration of concoidal fractures, whereas the coarse grained variety have relatively moderate to low concentration of non-concoidal fractures. In addition to above, there are columnar, loose-jointed rocks on one side of the top of the sledge. The basaltic rock as such is strong but with the above features it becomes weak and susceptible to fall. The weathering as can now be considered as moderate but the fracturing on the rock is considerably high. The loose material, debris, chips and foreign matter must be completely removed.

In view of the above, two alternative methods were suggested. Under the first alternative, the entire vertical face of the sledge was recommended to be stabilized with steel fiber reinforcement shotcrete (SFRS) of 70mm thickness and wrap-up the whole sledge from the top to bottom on both sides (Expressway and National Highway – 4) with steel rope net of aperture size 300mm X 600mm. The SFRS provides measures to prevent the rock blocks moving from the slope and also prevent the weathering of the rock slope.

The steel rope net of aperture size 300mm X 600mm should be anchored at the top. For installing the steel rope net on the slope it is required to dig a trench of 30cmx50cm at a distance of 1.5m from top of the cliff. In the trench, iron rods of 0.5m are inserted from the bed of the trench. After inserting the rods the holes are grouted with cement concrete. Subsequently, the steel rope net of desired length is laid and the trench is filled with cement concrete for anchorage. The steel rope net is spread on to the vertical face of the slope up to the toe on both sides of the sledge. Fixing the steel rope net to the slope surface either by means of expansion bolts or grouted bolts at 3m intervals is to be done. The length of the bolt should not be less than 0.5m. This kind of stabilization solution will control rock block directly falling on to the expressway.

As observed during the course of the field investigations there is no provision made for draining of collected water and also preventing the rain water from percolating into the fractured rock mass. It was, therefore, suggested to seal the rock fractures by the cement grouting and shotcrete of 50mm thickness on the entire top of the sledge so that water does not enter into the rock surfaces. Catch water drains are also provided all along the top of the sledge with proper slope so that water drains into the catch drain, through which a connecting pipe drain of 15cm diameter could drain it out. The outlet of the pipe opens into the already provided roadside drain on NH-4.

10. CONCLUSION

The Amrutanjan Bridge is one of the strategic and important trouble areas on Mumbai – Pune expressway. At this location both expressway and National highway are passing one above the other. There is no additional space to catch rockfalls on the expressway. Because of limited space and field restrictions it was recommended to MSRDC to shotcrete along with laying rope net on both sides of vertical sledge. Besides, shotcreting and provision of drainage measures were recommended on top of the sledge.

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References

CRRI (2006). Study of Landslide and Rockfalls on Mumbai – Pune Expressway submitted to MSRDC, CRRI S&T Draft Final Report.

Hoek, E. and Bray, J. (1981). Rock Slope Engineering, The institute of Mining and Metallurgy, London.

Goodman, R.E. and Kieffer, D.S. (2000). Behavior of Rock in Slopes, Geotechnical and Environmental Engineering, Vol. 126, No.8, pp. 675-681.

Goodman, R.E., Shi, G.H. (1985). Block theory and its applications to rock engineering, Prentice – Hall, Englewood Cliffs, N.J.

Jesse. W. D. and Shakob Abdul (2005). Containment measures for slope hazards: Evaluation of the Effectiveness of Catchment Ditches Along Ohio Roadways, J. Transportation Research Record, Vol.1913, pp. 196-204.

Navaratnarajah Sasiharan, Balasingam, Muhunthan, Shanzhi Shu, Thomas C. Badges (2005). Analysis of Global Stability, Anchor Spacing, and support Cable Loads in Wire Mesh and Cable Net Slope Protection Systems, J. Transportation Research Record, Journal of the Transportation Research Records, Vol.1913, pp. 205-213

MSRDC (1995). Report on Feasibility study for Bombay-Pune Expressway– carried out by Rites and Scott Wilson Kirkpatrick consulting Engineers, U.K

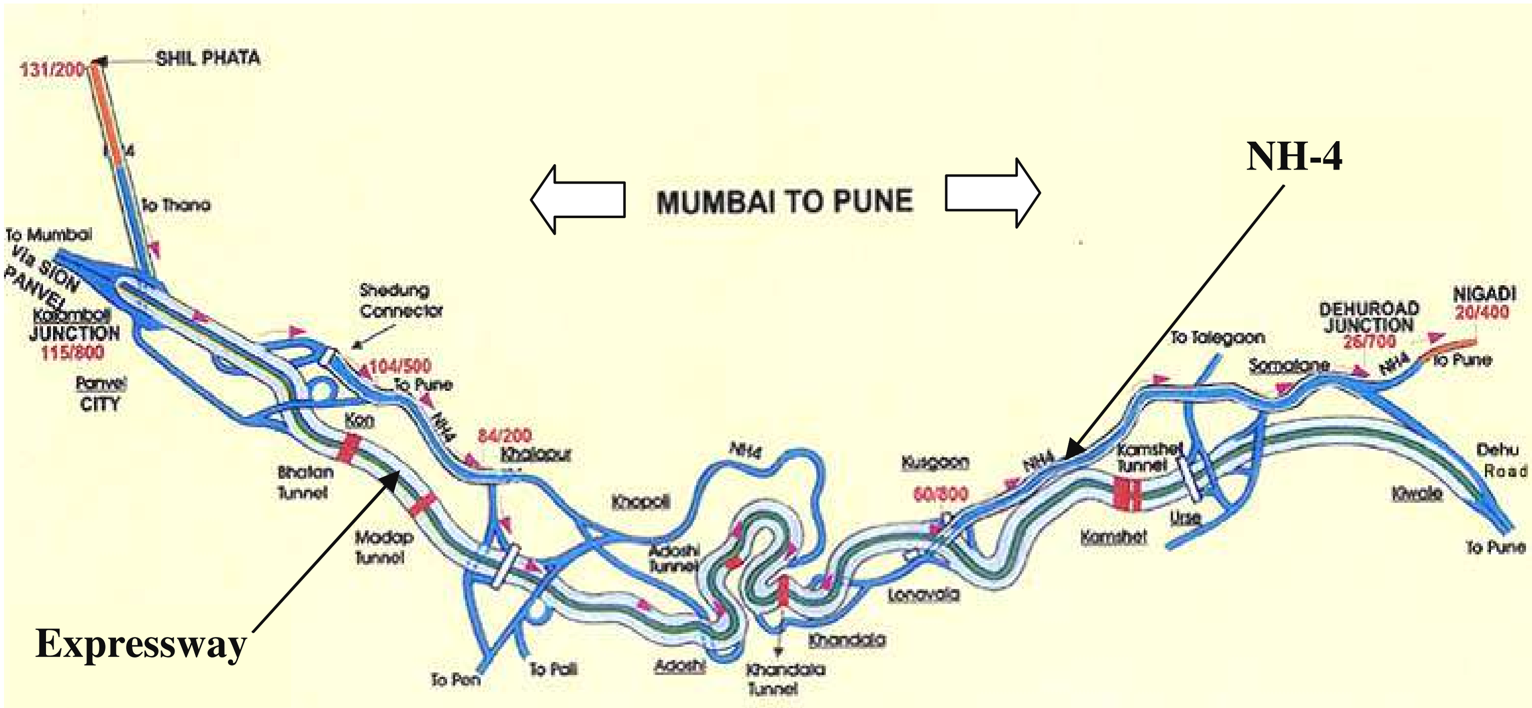

Fig. 1 – Mumbai-Pune expressway