Geological feasibility and slope stability analysis under GIS environment for rail route alignment

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Abstract: Rail Route Alignment in hilly terrain is a difficult task to implement as several natural constraints poses threat to the safety and stability of the alignment. The conventional methods followed to find out the final location survey or the feasibility analysis for alignment is time taking consuming. Some times, due to inaccessibility of the terrain it becomes impossible to carry out such works.

The construction works in hilly terrain, which are associated with the proposed alignment, are not same as carried out in plane areas due to a vast contrast between the two areas. Different geological structures such as faults, thrusts, synclines and anticlines are a big problem to carry out normal construction practices. Thus for a safe and stable railway route in the unstable hilly areas, it is required to carry out the feasibility analysis of the proposed alignment to assist the policy makers for a successful implementation of the alignment.

In the present work Remote Sensing and GIS has been successfully used to carry out geological feasibility and slope stability analysis for rail route alignment work.

Introduction

Any large-scale construction project in a mountainous terrain is totally different from the same in planes. There is a vast contrast between the properties and characteristics of these two areas, which poses lot of problems in a hilly terrain in comparison to the plane areas.

There are 100's of proposals for new rail line or gauge conversions are pending in India. Every year only 40 to 50 proposals are studied for techno economical feasibility of the project using conventional methods due to the working difficulties in conventional methods. In the present work feasibility analysis was carried out for the proposed rail route using some modern techniques of modern techniques of Remote sensing and GIS by delineating the areas of natural hazards and also to find out the geological constraints associated with the proposed alignment, tunnels and bridge locations.

Rail route alignment: some basic consideration

For any rail route alignment, some basic consideration plays an important role and determines its extent, shape and stability (G. Waren Mark, 1991). These considerations are interrelated and dependent on each other. Some important considerations are:

Political and strategic considerations

The development of a new railway line may also be a part of strategic consideration, i.e., a part of a long-term strategy for the development of the country or the region. It may also be planned for the development of some backward areas with no or little conveyance; connecting new trade centers and shortening existing rail lines or both (G. Waren Mark, 1991).

Engineering considerations

Any railway line and its alignment largely depend upon the topography, particularly when it passes through a rugged topography. Once, a decision has been taken during preliminary investigations about the general feasibility and desirability of a railway line, surveys are undertaken before the construction of a new line.

Geological considerations

This becomes extremely important in case of a rail route alignment in mountainous region where topography is difficult and a diverse condition of geologic formations and structures occur as railway line in hilly terrain generally possess a good number of tunnels and bridges.

Study area

The area of study is confined to a 222 kms narrow strip (NW-SE) in the Northern part of the India. The area exhibits a typical mountainous terrain starting from average elevation of 500 m. The highest contours encountered are 2200 m. The elevations are quite variable throughout the route.

Geology of the area

The area exhibits mainly four types of sequences e.g. Siwalik Super Group, Muree Formation, Subathu Formation, Pre-tertiary sequence (mainly Limestone and dolomites). Fig.1

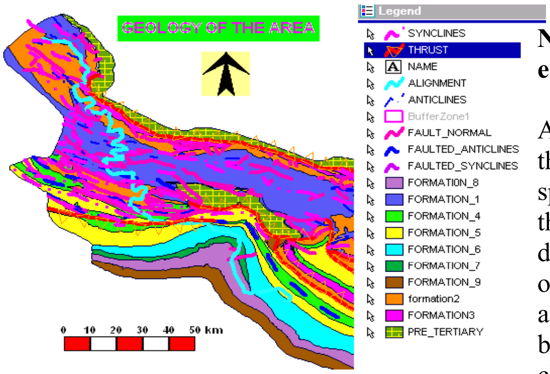

Fig. 1 – Geology of the area (Source ONGC, 1990)

Landuse pattern

Nine landuse category has been observed in the area viz. Dense Forest, Light Forest, Grasslands/Grazing Grounds/Sparse Vegetation, Agricultural Land, Barren Land, Rivers and Settlements, on the basis of available toposheets and satellite images and corresponds to level II classification of Anderson.

Methodology

Steps Followed:

a) Digitization of Existing Maps
b) Topology Building
c) Data Base population
d) Secondary Map Generation

After the database population (attached with different graphical elements) several secondary maps were derived from topographical map using GIS functions and database queries The secondary maps derived are:

(i). Slope map
(ii). Aspect map
(iii). Geological thematic map
(iv). Geological Structure map
(v). DTM of the study area

Landuse map (after classification) and lineament map was created from Satellite Data and the attributes were incorporated into database.

Methodology for slope stability analysis

Unstable slopes or landslide zones has been identified with the help of IRS 1C, LISS III (band 2,3, &4) and PAN images and existing maps.

Data Integration

The data derived from the various sources has been incorporated into a common GIS environment for Analysis and the final GIS product has been used for analysis.

Numerical rating and Weight Calculation of Geo environmental Theme Units:

After the analysis of the different thematic units, using the Geomadia (GIS package) analysis tools and different spatial functions along with attribute data associated with these units, certain output map has been produced depending upon the queries and analysis tools used. The output maps one;

a) Landslide location map
b) Landslide Hazard map
c) Vulnerable slopes in a 500m buffer of alignment.
d) Type of slopes at tunnel & bridge locations.

For determination of the landslide prone areas and L.H.F. calculation, a statistical method is used and the steps followed are described below:

Steps for Numerical Rating & Weight Calculations

i) Each thematic map was superimposed over the landslide map. The number of landslides occurring in each unit within a thematic map was noted and a landslide distribution chart was prepared. All the data were stored in the database for retrieval and analysis.
ii) The area occupied by various theme units and incidence of landslide occurrence per km square within the their unit was calculated.
iii) Landslide Hazard Rating/factor (L.H.F.) were calculated for each unit various themes to make hazard assessment or zoning. A empirical landslide hazard index which shows susceptibility in terms of landslide hazard factor (L.H.F.) of the individual units is derived as follows:

$$\text{L.H.F.} = \frac{\text{Landslide incidence in a particular unit}}{\text{Average landslide incidence in various units within theme}}$$

A value of LHG > 1 indicates that a particular theme unit is more susceptible to landslides than the average, while a value < 1 represents more stable slopes. A value of L.H.F. 1 implies that the subcategory has an average landslide incidence (Gupta & Joshi, 1990).
Using the above criteria the L.H.F. of various theme units was calculated and weight was assigned depending upon the L.H.F.

Methodology for analyzing geological feasibility

Landslide hazard map has been combined with a Geotechnical constraint map to get a common map out of these two. A close correlation has been found between different theme units and the frequency of landslides in the study area. The findings are as follows:

(i) Lithology
In the study area the 10 major lighologic units are mainly composed of Sandstones, Shale, Quartzite,

Mud stones, Limestone, Dolomites, Shists and gravel.

(ii) Distance from nearest lineament
Degree of fracturing and shearing of the associated rock types has been taken into consideration to determine the stability or the susceptibility of the locations around the proposed route. It has been observed that the major landslide locations are either very close or in the vicinity of major fractures, faults or thrusts. The landslide frequency progressively decreases with increase in distance from these discontinuities.

(iii) Drainage
The visual interpretation and field observation indicate a distinct association between the sharp convexities of the major river meanders and landslides occurrence. A total of 89 landslides occur in the proximity at the major river (<500). Of these 66 are associated with the convex banks of the sharp riverine meanders as against concave (5) is attributed to the toe erosion induced by the flowing water current on the convex banks of the meanders.

(iv) Slope
The slope map derived from DTM has been divided into 9 major sub-divisions (0-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90). The frequency of landslides in various slope categories has been calculated and has been found that the maximum number off landslides occurs in slopes range $50\text{-}60^0$ (38), followed by $40\text{-}50^0$ (26) and 60-70 (24) others are normal.

(v) Landuse
Among the eight-landuse classes a total of 148 landslides has been observed. It has been observed from the distribution of landslides in different landuse units, that more than 80% landslides occur in less or no vegetated areas.

Results for geological feasibility

After building up database with the help of GIS queries location of the tunnels and bridges, which fall, in vulnerable areas was found out. Altogether, 118 tunnels and 294 bridges has been proposed throughout the route out of which 19 tunnels 35 bridge locations has been found vulnerable to normal construction practices as far as safety and stability is concerned (Fig. 2).

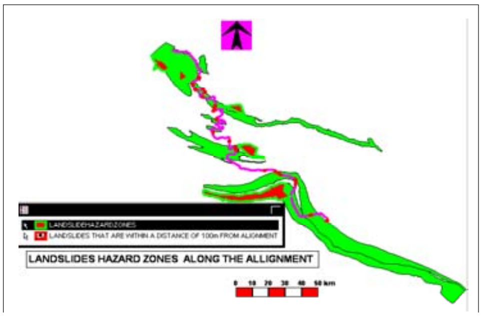

Fig 2 – Landslide hazard zonation map

Conclusions

The main findings of the whole study are:

(i). Satellite data could be used successfully to detect existing or probable landslide locations.

(ii). The aid of GIS tools for analysis of Landslides along a particular route (alignment) is very helpful.

(iii). For analyzing the spatial features for feasibility of the entire route and the special constructions such as tunnels and bridges, GIS tools are of enormous importance.

(iv). The susceptibility index of different Theme units shows that the slope range between 50-60 degrees, formations containing friable rocks (shales, mudstone, alluvium etc), convex banks of major reverine courses and areas within a range of 1 km from lineaments are most susceptible areas for present and future landslides.

References

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