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A tentative appraisal of the environmental impact of railway construction in mountain areas

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Abstract It is well known that engineering activities associated with mountain railways, such as siting, construction and operation are influenced by various mountain hazards. However, discussion of the appraisal of their impact on the mountain environment, such as changes in geomorphic features, destruction of vegetation and arbitrary placing of immense spoil heaps which may induce or increase landslide and debris flow activity, is rarely found in documents. By analysis of case histories, this paper proposes a semi-quantitative method for applying standards for appraisal of the impact of railway construction on mountain environments and for implementing control measures. It can be used to select alternative options for railway development in feasibility studies and to avoid or alleviate degradation and to maintain the ecological balance of the natural environment.

INTRODUCTION

In China, the geomorphic and geological characteristics of mountain lands are very complex and various mountain hazards occur due to intensive neo-tectonic movement and serious soil erosion involving landslides and debris flows etc. Before 1950, Chinese railways were constructed primarily on flat land and after 1950 expansion into mountain areas occurred. It is reported that China now has an operational railway network more than 57 000 km long which ranks fifth in the world. However, the interrelationships between the ecological balance of mountain environments and railway construction were poorly understood in the past and few ameliorative measures were applied. However, as a result of numerous problems associated with mountain hazards, it was gradually recognized that the siting, construction and operation of railways in mountain areas must take account of mountain hazards and potential impact on the mountain environment.

THE IMPACT OF RAILWAY CONSTRUCTION ON MOUNTAIN ENVIRONMENTS

The degradation of mountain environments is a widespread problem in China, and the need to maintain the ecological balance of such environments is of critical concern. Degradation leads to the development of geological hazards such as debris flows and landslides associated with the development of soil erosion. Newly-built railways in the mountain areas are bound to lead to changes in geomorphic features, destruction of vegetation and the arbitrary placing of immense quantities of spoil. These impacts will aggravate the degradation of the mountain environment if appropriate treatment countermeasures are not introduced. For example, in the Qinlin mountain section of the Chengdu-Baoji railway and in the Dabashan mountain section of the Xiangfan-Chongqing railway, annual soil erosion averages 8500 t km^{-2}.

LANDSLIDES

Landslides represent about 80% of the geological hazards occurring in mountain lands and are a primary hazard to railways. It is reported that more than 4000-5000 landslides extending over a total length of 500-600 km have occurred in the vicinity of railway lines since the 1960s. Railway lines particularly affected include those from Baoji-Chengdu, Baoji-Tianshui, Chengdu-Kunming, Changsha-Guiyang and Xiangfan-Chongqing.

The railway line in the Baoji-Guangyuan section of the Baoji-Chengdu route passes over the Qinlin mountains where the natural slopes are mostly in limited equilibrium and are frequently undercut and seriously eroded by rivers. When assessing various possible routes for this railway line it was suggested that the line could be integrated successfully into this dangerous and difficult section. However, little further thought was given to potential problems at that time, and the development of landslides has increased. For instance, on 6 January 1959, a landslide involving 300 000 m^3 of debris occurred below the cutting through the Lijiahe landslide (km 122). The slide distance exceeded 800 m and the railway was pushed into the Jialing River. On 4 September 1981, at km 133 a landslide and rockfall carried 200 000 m^3 of debris into the Jialing River. The river was dammed for 12 minutes and the water level rose by 15 m. The railway traffic was held up for 15 days because the rails were pushed to the opposite river bank. Thirteen passengers died during this event. Some hazards, particularly rockfalls, can be attributed to rock masses loosened by the shock of heavy blasting during construction. For example, the rockfall which took place at Guanyinshan railway station on the north slope of Qinlin mountains.

The landslide in the Baoji-Tianshui section occurred on 27 September 1963. A mass of 400 000 m^3 slipped more than 400 m and caused the destruction of the railway line, houses and electricity poles over a distance of 200 m. Traffic was held up for 169 h. Another landslide occurred in the deep cuttings of the Baoji-Tianshui section (km 1357) on 29 November 1981. A mass of more than 600 000 m^3 caused the destruction of a cut-cover tunnel 75 m in length and covered the railway for a distance of 66 m outside the tunnel. Traffic was held up for 314 h.

In order to ensure the safety of railway operations, China has expended considerable sums on hazard control since liberation. For example, expenditure on the control of mountain hazards in the Guangyuan-Baoji section approached the level of the original investment on railway construction during the period 1957-1984 and the expenditure on the Baoji-Tianshui section amounted to 4.3 times the construction costs during the period 1949-1984.

DEBRIS FLOWS

Debris flows develop mainly in regions with strongly weathered and fractured rocks, sparse vegetation, unconsolidated slope regolith and heavy rainfall. Debris flows are one of the most serious geological hazards for the railways of China. Reports indicate that there are 1386 large and medium scale debris flow gullies which currently threaten the safety of the Chinese railways. Debris flow incidents occurred on more than 2000 occasions between 1949 and 1983. Traffic was held up for 435 days, 27 bridges were damaged, 22 station buildings and six tunnels were inundated, and four freight trains and one passenger train were derailed and overturned.

During the survey and design of the Chengdu-Kunming railway, the engineers were primarily concerned with route selection and protection against existing debris flow hazards. They neglected the environmental impact of railway construction and operation, and of industrial and agricultural development along the railway and did not produce a complete forecast of potential hazards and the protection measures required. As a result, debris flows represent a serious geological hazard on the Chengdu-Kunming railway. Debris flows from 47 gullies along the route occurred more than 60 times during the period 1970-1981. On 9 July 1981, debris flows involving 840 000 m^3 of material including many rocks of more than 100 m^3, took place during a single hour in the Lizhiyida Gully. Bridge piers were destroyed, passenger train no. 422 was overturned, and 10 passengers died during this accident.

There are many debris flows along the Baoji-Tianshui railway, the Yangpingguan-Ankang railway and the Guiyang-Guilin railway. In 1950, the I-beam bridge with three spans of 4.2 m was pushed into the Weihe River by a debris flow. During reconstruction of the bridge in 1951, the route had to be upgraded and the new bridge had to be increased to 20 m in length and four spans. However, a debris flow in 1954 deposited 2.8 m of material under the bridge, and the overall volume of deposits amounted to 30 000 m^3. These historic cases of incidents causing danger to railway operation and human life emphasize the problems associated with the environmental impact of railway construction in mountain areas.

EVALUATION METHODS AND PROCEDURES

Since the First National Environment Protection Meeting, which was held in 1973, many laws, regulations and guidelines have been issued by the State and the Ministry of Railways. In these it has been clearly stipulated that particular attention should be paid to the need to avoid damage or destruction of the mountain environment, and to safeguard the ecological balance as well as to the need for restoration work during the various stages of railway construction. This provides a basis for developing principles for preventing the deterioration of mountain environments.

Macroscopic forecasts

Engineering geologists involved with railway construction treat engineering works as the central consideration and give little attention to the reaction and deterioration of the environment. Although some measures have been introduced for preventing geological hazards, no overall macroscopic forecast and appraisal system has been developed to counter the degradation of mountain environments along the railway.

Factors influencing environmental degradation

Bridges and tunnels represent 7% of the total railway construction in China and the subgrades (including culverts) account for 93%. It is therefore clear that engineering works associated with subgrades, bridges and tunnels are the main factors influencing the degradation of the mountain environment. Engineering practice indicates that the landslide collapses mainly affect the subgrade and that debris flows cause damage primarily to bridges and tunnels.

Protection and restoration measures

During the survey, design and construction of railways, the following measures should be taken to avoid damage to the mountain environment:

(a) Investigations of the distribution of landslides, debris flows etc in the immediate area and their stage of development.

(b) Studies of engineering control measures.

(c) Use of environmental protection measures during the cutting and refilling of the subgrade and during bridge and tunnel construction.

At the same time, the ecological balance should be protected to prevent the deterioration of the mountain environment through measures such as planting of vegetation, restoration of runoff areas, gullies and rivers, and the treatment of the large areas of spoil.

APPRAISAL STANDARDS

Standards for appraisal of the environmental impact of railway construction in mountain areas can be based on the requirements of the document *Management Procedure for Environmental Protection in Projects of Railway Capital Construction and Technical Measures* (1983), in which it is stipulated that "the destruction of the natural environment and the ecological balance should be avoided as far as possible and that attention should be given to the protection and restoration of the natural environment and ecological balance when assessing the options for newly-built railways". Feasibility studies must therefore include the following:

(a) Poor geological conditions such as landslides and debris flows etc. should be avoided. If impossible, all feasible control measures, both technical and economic should be implemented to maintain or restore the ecological balance of the natural environment.

(b) Damage to the mountain environment shall be reduced as far as possible during the cutting and filling of subgrade engineering works and control measures should be introduced to maintain the stability of unstable cutting slopes. Slope cuttings at tunnel portals should be avoided as far as possible.

(c) Bridges rather than culverts should be used as far as possible in areas subject to debris flows. The line itself should not pass through the debris flow zone and ideally should pass through the safety zone far away from the alluvial fan.

(d) Programmes designed to avoid degradation of the mountain environment should be developed and control measures to maintain and restore the vegetation should be implemented.

The above can be used to provide tentative standards for appraisal of environmental degradation. Such standards can be classified into:

(i) Class A, which must meet all the requirements listed above and which should be applied to national trunk lines, Class I lines, and lines passing through protected regions, scenic zones and famous historical sites designated by the state.

(ii) Class B, which basically meets all the above requirements and can be applied to Class II lines and Class I local railways.

(iii) Class C, which basically meets the above requirements with the exception of (d) and is normally applicable to local railways.

CONCLUSIONS

The relationship between railway construction and the ecological balance of the natural environment must be taken into account in feasibility studies of various alternative railway options. Environmental impact appraisal should be carried out on the basis of the relationship between engineering construction and engineering geology. If insufficient attention is given to avoiding damage to the natural environment and its recovery from damage in the engineering activities associated with mountain railways such as siting, design and construction, the degradation of the mountain environment will increase and endanger the safety of railway operations. The tentative standards for appraisal of the environmental impact of railway construction in mountain areas outlined here can be used for selecting alternative railway options and for appraisal of various mountain hazards to avoid or alleviate degradation and to maintain the ecological balance of the natural environment.