SLOPE STABILITY IN MOUNTAINOUS ROADS IN IRAN. A CASE FOR REMOTE SENSING?

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ABSTRACT

Since its opening in 1963 the 100km mountainous section of the Haraz Road in North Iran has presented severe problems of maintenance for the highway engineers. Problems relating to the geology, topography and climate have combined to create almost permanent difficulties in keeping the road open for traffic. Numerous local and ad hoc solutions have been attempted, but these have been mostly short term and have proved to be not very cost effective.

It is now realised that the many and separate problems occurring along the entire road must be viewed in their entirety and treated as a single problem. Only by viewing the problem as a whole can the most cost effective methods be properly implemented. The first step in this study is to gather those data which are relevant: to identify the type, location and magnitude of the problem. This involves a rigorous study of a number of environmental factors in an attempt to identify their relationships.

The first stage of this research project is to investigate the extent to which remote sensing - particularly the use of satellite imagery - might be a useful source of information.

With this in view (four) Landsat computer compatible tapes have been studied in an attempt to identify seven categories: six different geological formations and forest. This paper gives the results of a digital analysis of sample areas along the road.

It clearly shows that by adopting different methods of analysis the results can be considerably improved, and that remote sensing systems have considerable potential to the highway engineer. This potential will be further examined and exploited in subsequent stages of this project.

Introduction

The Haraz Road, (180 km in length) joins Tehran with the town of Amol on the Caspian Sea. Along 100 km of its route it passes through the Alborz Mountains which rise to a height of 2700 metres and have extensive snow cover in the winter. Figure 1 shows the location of the road in northern Iran.

The construction of the road began in 1937 but was held up during the last world war and was finally opened to traffic in 1963.

Because of the considerable difficulties of access, virtually no site investigations were carried out prior to the construction of the road. The result of this has been severe problems in maintaining the road in a suitable condition for traffic.

The geology, slopes and climate have combined to create an almost permanent problem along the entire upland area of the route. Various ad hoc improvements have been made over the years, and the road now contains fourteen drilled tunnels, four avalanche galleries, one wind tunnel and fifteen rock shutes.

Surface rock slides and landslides created such difficult and expensive problems of maintenance that the Iranian authorities decided it would be better to close the Haraz Road and build another to replace it. However, the road is now quite heavily used and is an essential link between all the towns and villages along and near its route. Furthermore, it is the only main access route to coal mines and a major reservoir which supplies Tehran with water.

The experience of the last 20 years, has shown that the short-term, cosmetic remedial work carried out has been expensive and not very effective. It is now realised that a comprehensive survey, inventory and study of the road is essential as a first step towards the design of more substantial and cost-effective engineering works. Figure 2 shows the location and type of hazard which is currently affecting the slopes along the upland routeway of the Haraz Road.

One possible solution to the problem of data acquisition is to investigate the extent to which remotely sensed imagery might provide useful information. It is to this end that this initial study is directed, the first stage of which is outlined here.Some remotely sensed material of the Haraz Road has been acquired consisting of multidated Landsat tapes and images.

Topographical and geological maps, and a number of site reports compiled by the Geological Survey of Iran, (and some by one of the authors), provide useful ground information. In addition some additional field work was carried out in Iran during the summer of 1982, when many ground mono and stereo photographs were taken and rock specimens collected.

The 'problem' sites defined in Figure 2 vary in length from a few metres to several kilometres, and they have been recorded in the reconnaissance field work carried out.

Of the several problems mentioned above, a typical example is the situation at km 57 near Shangoldeh. At this location, on a slope of some 35 degrees, a landslide which developed many years ago has recently moved some 20 metres both laterally and vertically. The village of Shangoldeh is located on the landslide and during these recent movements tension cracks, 600 mm wide, appeared in the village area. The advice to evacuate the village was ignored and further movement and damage, associated with the March 1983 earthquake, resulted in some loss of life.

The slide, which measures 700 metres by 300 metres and is clearly visible on the aerial photograph (Fig 3), has moved the highway towards the Haraz river where the downslope toe is continuously removed by fluvial erosion. The geology consists of Quaternary Damavand volcanics (mainly andesite flows) overlying the lower Jurassic Shemshak formation (dominated by mudrocks) which dips downslope at some 45 degrees. The situation is aggravated by the hydrogeology, where infiltration of rain, snowmelt and irrigation waters rapidly reaches the Shemshak strata where they become perched. Faulting and seismic activity also contribute to a considerable degree to the instability.

Due to topographic constraints there is no alternative road line in this vicinity and the only means of maintaining the highway is to stabilize the landslip. This can be accomplished only by massive improvement in run-off/infiltration control and drainage. The official recommendation is currently, that the village should be abandoned, and the road maintained by minimal remedial works at frequent intervals.

Methodology and Results

Four Landsat scenes are available for this study. These are dated:

1- 4th September 1972
2- 7th April 1975
3- 13th July 1977
4- 28th April 1978

The two scenes of September 1972 and July 1977 were selected because they were totally free of snow, except for a small area on the peak of Mount Damavand.

From each of the two Landsat scenes twenty six subscenes were selected covering that part of the Haraz road which is included in the study area. These subscenes were enlarged to a scale of 1:100,000 to coincide with the geological maps. Each subscene covers an area of forty by forty pixels and was stored on magnetic tape. The pixel values were then printed out for each subscene. These data were recorded by Landsat 1 and 2, and it should be noted that bands 4, 5 and 6 employ photomultipliers which measure in the range 0 to 127, but photodiodes for band 7 measure in the range from 0 to 63. To provide compatibility the band 7 pixel values have been doubled.

Table 1 shows the categories which were selected for study, comprising six types of geology and one of vegetation (forest).

Within these subscenes one or more six by six pixel grids was selected for each of the seven categories. The average pixel values for each MSS band were then calculated and these, with their standard deviations are shown numerically in Table 2, and diagrammatically in Fig 4.

Figure 4 shows considerable spectral overlap between the different categories, therefore multiple band relationships were investigated in an attempt to provide discrimination between categories. The problem of using the DN values is that they are affected by a number of variables, some of which are of unknown magnitude. It is necessary to reduce, or if possible eliminate, the effects of these variables in order to obtain a DN value that more accurately relates to the true reflection from a particular feature.

We know that the reflectance from a black body (or deep shadow) should equal zero. The actual DN values recorded from deep shadow can therefore be regarded as due to a combination of environmental factors which are given the general title of haze. In the samples measured in this study the average DN 'haze' value for bands 4,5 and 6 was 20, and for band 7 was 16 (8x2).

The closeness of these haze values meant that the haze factor could be substantially reduced by subtraction of the recorded band values. The results of these subtractions are shown in Table 3 and Figure 5.

A common stability problem occurs where the Quaternary volcanics (5-Lt) overlie the Jurassic Shemshak formation (1-Js) as at Shangoldeh. The volcanics are fairly easily weathered and soon break up. This together with the rapid infiltration of water which perches on the underlying Shemshak Formation creates very unstable conditions and makes this particular geological boundary of much importance to the roadway maintenance.

One immediate objective is to identify which band, or combinations of the MSS bands, permit the best discrimination between these two formations.

The pixel values associated with these formations (training areas 1 and 5 in Fig 4 and Table 2) show considerable overlap with the other training areas selected, and are not uniquely diagnostic.

However in band 5 the pixel values of the Shemshak formations do not overlap any of the other geological types and consequently is uniquely identified.

Figure 5 shows that in the band subtractions the Quaternary volcanics are moderately separated from all the other types of rocks and it is most clearly distinguished in B6-B5 and particularly in the B7- B4, combinations.

Forestry - the only non geological category - shows some interesting spectral characteristics. In both the single bands 4 and 5 it is very clearly distinguished from all the geological categories. Figure 5 shows that forestry is even more clearly defined, and only just overlaps with other categories in one case i.e. B6-B4. Elsewhere it stands out very clearly on its own.

The Upper Jurassic Series (4-J1) and the Cretaceous Sediments (6-K2) both show very similar distribution patterns (Fig. 4), and both show very high reflectance values. The reason for this is that both are similar limestone lithologies although different in age. The only other area which can be differentiatad is the Cretaceous volcanics (2-Kv) which are characterized by moderately low brightness values in all the bands with bands 4,6 and 7 showing no overlap.

Some interesting results are beginning to emerge in an attempt to differentiate the various categories initially selected. Using pixel values alone and in simple manipulations, it is possible to identify forest, and to differentiate between certain rock types of geology.

In an area as extensive, inhospitable and often inaccessible as the Haraz valley, the possibility of deriving useful information by remote sensing methods is very attractive. This highway study is the first of its kind to be undertaken in Iran and its main task is to assess the value of this relatively new tool as a source of useful data in the management and maintenance of a major line of communication and transportation.

Figure 1. Location of Study Area.

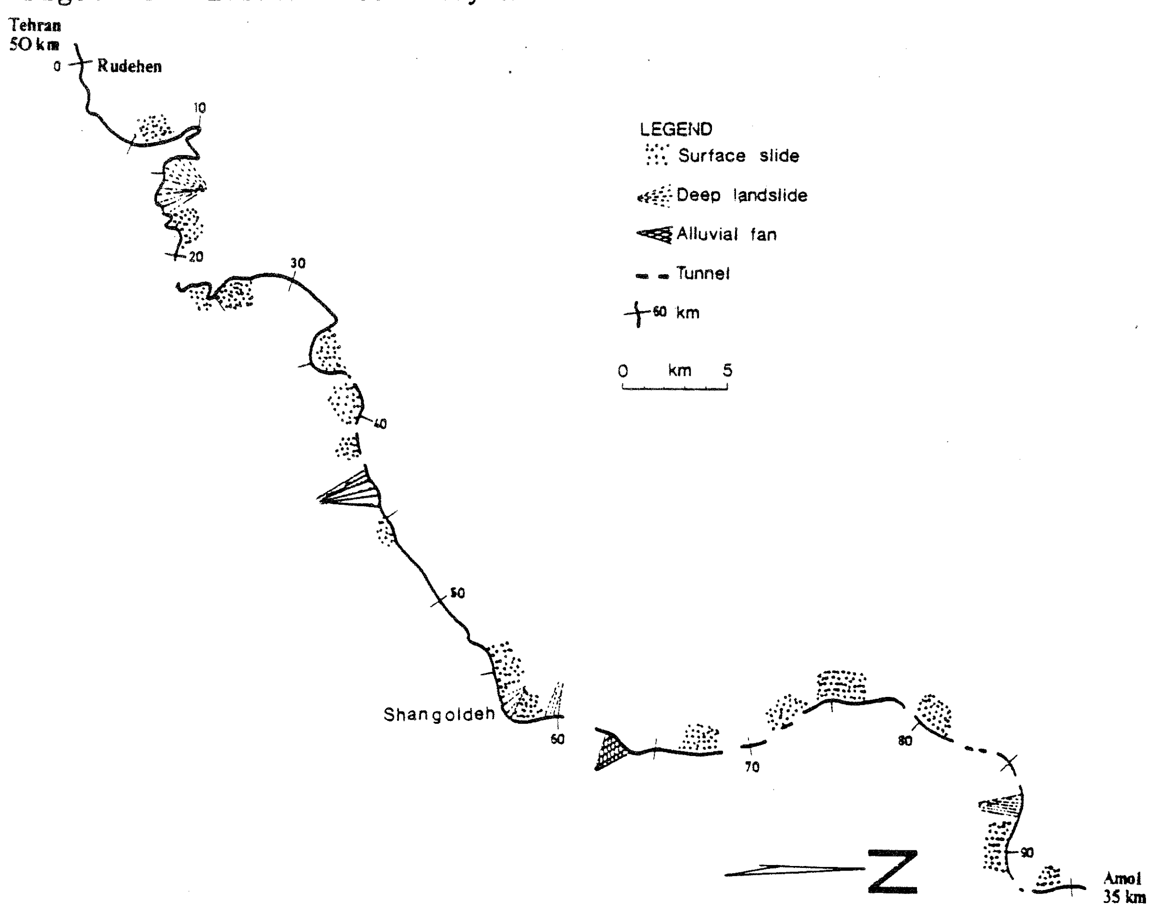

Figure 2. Details of the Haraz Road.

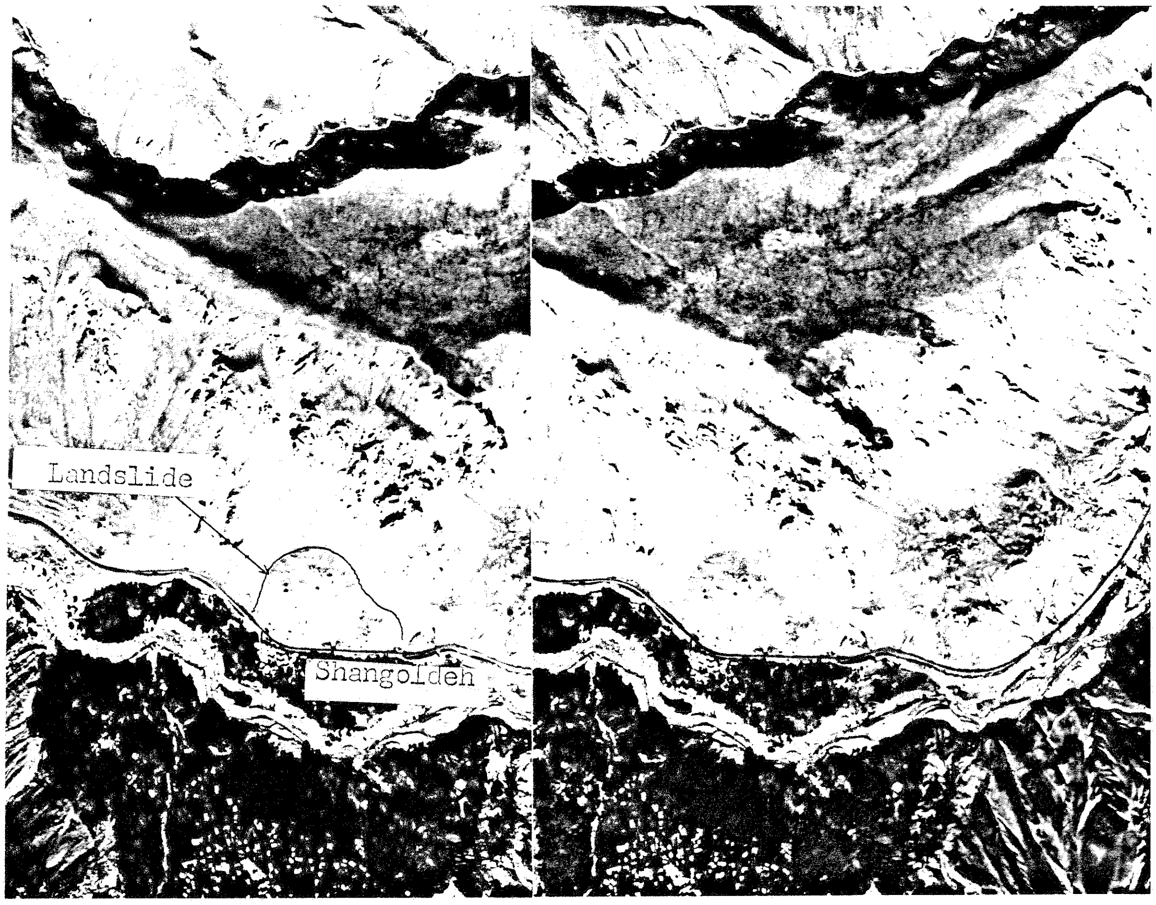

Figure 3. Stereo pair of aerial photographs of Shangoldeh. The landslide is shown in the bottom left corner.

No	Symbol	Description
1	Js	Lower Jurassic sediments: dark shale, sandstone, coal and plant remains
2	Kv	Cretaceous volcanics: basic lavas and pyroclastics
3	F	Forest and dense vegetation
4	Jl	Upper Jurassic: well bedded cherty limestone
5	Lt	Quaternary lavas: mainly trachyandesite
6	K2	Cretaceous sediments: biogenic cherty limestone
7	Td	Recent terrace deposits: sand and gravels

Table 1. Description of Training Areas Selected.

Training areas		Band 4		Band 5		Band 6		Band 7	
Code	Size in pixels	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1 - Js	108	41.6	3.9	41.4	6.0	39.6	6.0	34.0	7.2
2 - Kv	36	37.4	2.7	35.8	3.8	33.3	4.3	27.5	5.2
3 - F	36	23.4	2.0	15.9	1.8	34.9	5.6	41.2	8.7
4 - Jl	108	53.1	8.8	59.1	11.9	56	10.9	49.1	11.3
5 - Lt	72	43.0	4.9	47.4	6.1	49.4	6.0	46.3	6.5
6 - K2	36	54.2	6.9	58.8	9.7	54.3	9.7	43.5	9.5
7 - Td	72	47.0	6.3	48.5	9.5	44.0	8.7	35.9	8.3

Table 2. Average Pixel Values for training areas (see Figure 4.)

Training areas		Band 5 - Band 4		Band 6 - Band 4		Band 7 - Band 4		Band 6 - Band 5		Band 7 - Band 5		Band 7 - Band 6	
Code	Size in pixels	Mean	S.D.	Mean	S.D	Mean	S.D.	Mean	S.D	Mean	S.D.	Mean	S.D.
1 - Js	108	-0.20	3.9	-1.98	4.8	-7.59	6.5	-1.79	4.4	-7.40	7.1	-5.61	5.3
2 - Kv	36	-1.62	2.8	-4.14	3.8	-9.93	5.3	-2.51	3.7	-8.3	5.4	-5.79	4.8
3 - F	36	-7.47	2	11.5	6.2	17.83	9.7	18.97	6.2	25.31	9.4	6.33	5.6
4 - Jl	108	6.0	5.7	2.85	6.3	-4.0	9.8	-3.16	4.8	-10.0	9.7	-6.85	8.5
5 - Lt	72	4.40	3.4	6.35	3.9	3.29	5.9	1.94	4.4	-1.11	5.2	3.05	6.3
6 - K2	36	4.58	4.3	0.08	4.9	-10.72	6.2	-4.50	3.8	-15.31	6.7	-10.81	5.1
7 - Td	72	1.44	4.5	-2.97	4.8	-11.17	6.1	-4.42	3.9	-12.61	6.6	-8.19	5.3

Table 3. Subtraction Pixel Values for training areas (see Figure 5.)

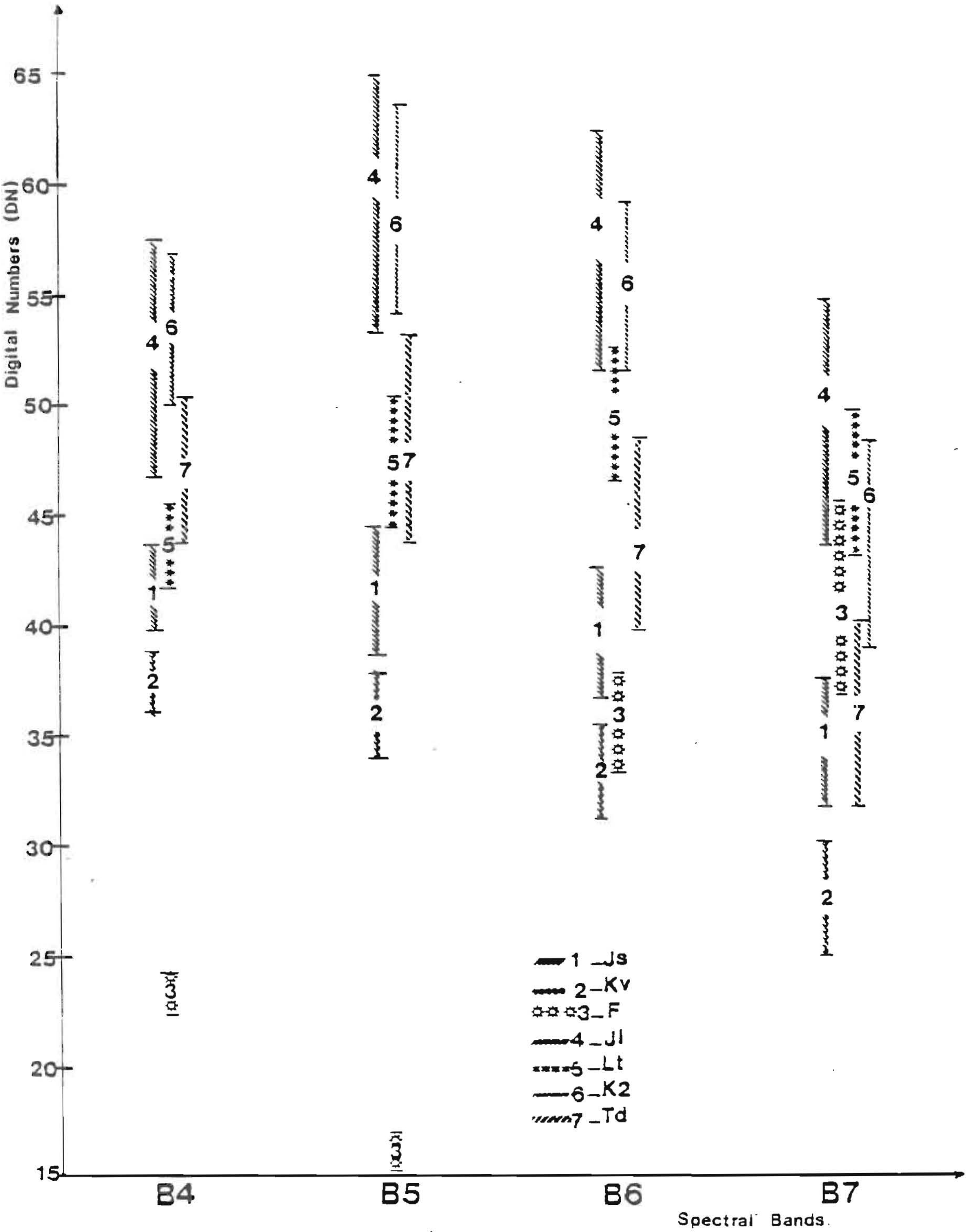

Figure 4. Pixel Values. Digital numbers are shown, with their standard deviations, for the seven chosen categories.

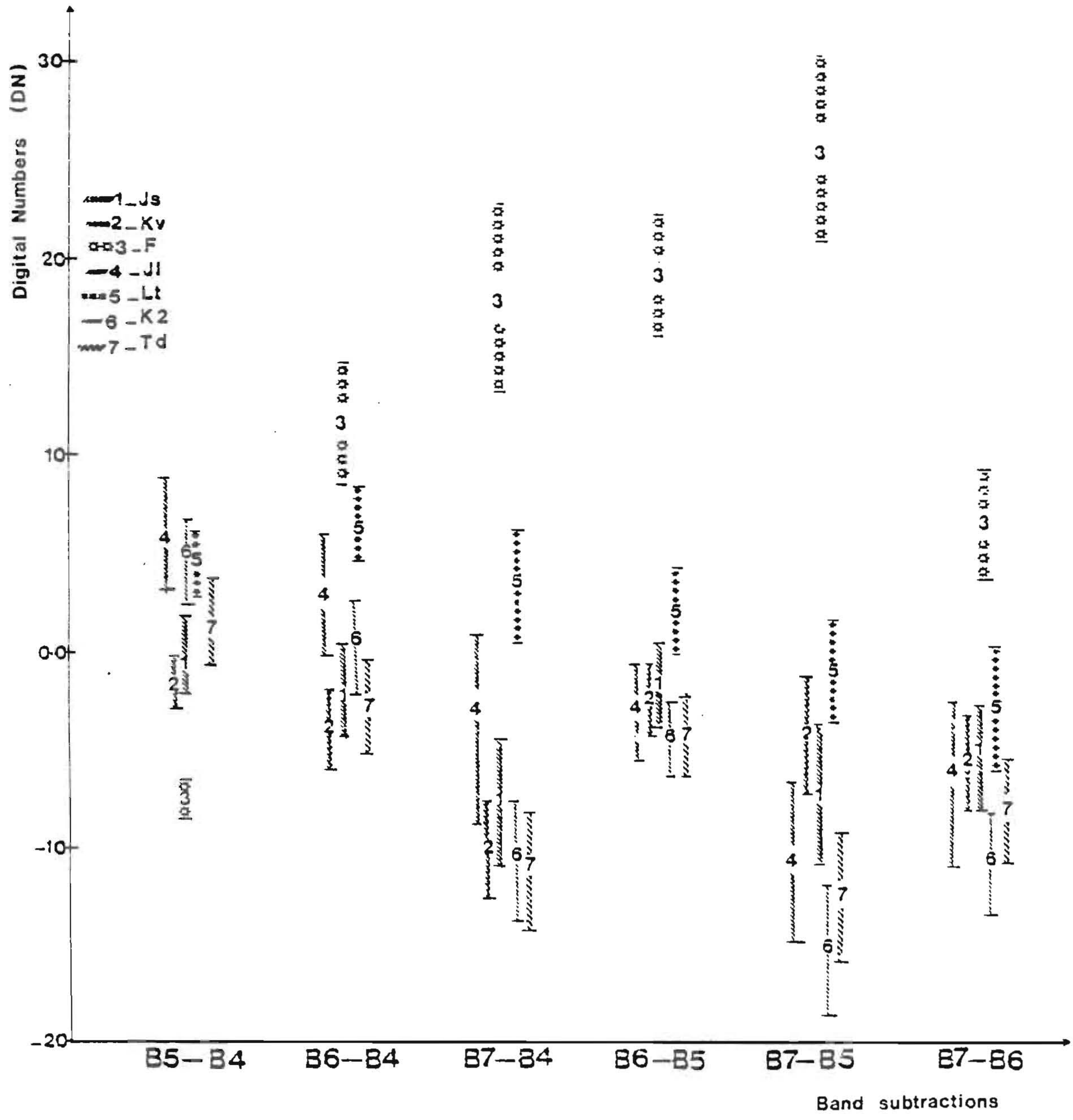

Figure 5. Subtractions of pixel values. Digital values for seven chosen categories.