*Journal of Nepal Geological Society, 2000, Vol. 22, pp. 517–524*

# Recumbent fold and deformed cut slope in the landslide-prone region of the Niigata Prefecture, Central Japan

**Tamotsu Nozaki[1], Katsumi Ookubo[2], and Toshio Yamamoto[3]**

[1]*CNK Geo-Technical Institute Inc. 581 Nishi-toheizoh Takaoka, Toyama 983-0824, Japan*

[2]*Japan Highway Public Corporation, Japan*

[3]*Konoike Construction Co., Ltd., Japan*

## ABSTRACT

The proposed Joushin-etsu Expressway passes along the western margin of the Takada Plain in the Niigata Prefecture, Japan. The Expressway runs through the eastern limb of the Nanbayama Anticline, which is composed mainly of Miocene sedimentary rocks. This part of the Niigata Prefecture is one of the well-known landslide-prone regions of Japan. Numerous prehistoric rockslides were identified during the preliminary investigations. Consequently, many additional studies were conducted and monitoring networks were established during the construction of tunnels and open excavations.

In order to obtain representative geotechnical data for one of the excavations, detailed geological mapping, geotechnical investigation, and monitoring of a cut slope deformation were conducted. The investigations revealed unusual geological features: a thick crush zone, interbedding of sandstone and mudstone, and a recumbent fold constituting the crest of an isolated hill. The cut slopes in the crush zone started to deform during the excavation, and continued even after the completion of the excavation.

We believe that the crush zone was developed tectonically, and the recumbent fold was formed as a result of the stress release induced by rapid erosion and gravity.

## INTRODUCTION

This paper presents the unique geological phenomena, which were observed during the Expressway construction. The Joushin-etsu Expressway connects the cities Nagano and Jouetsu in Central Japan (Fig. 1). The segment of the Expressway that was studied is approximately 12.5 km long and is located in the south of the Jouetsu Junction. It passes through the foothills of the Nanbayama Mountains, which are made up of Middle to Upper Miocene sedimentary rocks (Fig. 2) characterised mainly by flysch-type interbedding of sandstone and mudstone (Akahane and Kato 1989; Niigata Prefectural Government 1989). The Middle to Lower Pleistocene non-marine sediments or fluvial deposits cover partly the foothills containing older formations. The Lower Member of the Nohdani Formation (Upper Miocene sediments) is distributed in the southern half of the study area, whereas the Middle and Upper Members occupy the northern half. The Expressway route runs through the eastern limb of the Nanbayama Anticline, a major anticline in the region. The strike of the Middle and Upper Members of the Nohdani Formation is NW–SE while that of the Lower Member is essentially due N–S, and they dip to the east. The fold system in the southern part of the area is very complicated, and the area is also close to the intrusive body of Upper Miocene diorite porphyry (Fig. 3).

Numerous geotechnical problems were encountered during the construction of the Expressway. One of the most serious problems was the existence of prehistoric rockslides, which were exposed during the excavation. Most of them were not identified during the geological investigations before construction. The designed cut slopes were often modified due to the adverse site conditions, and some of the rockslides were reactivated by excavations. However, most of the reactivation did not result in serious problems.

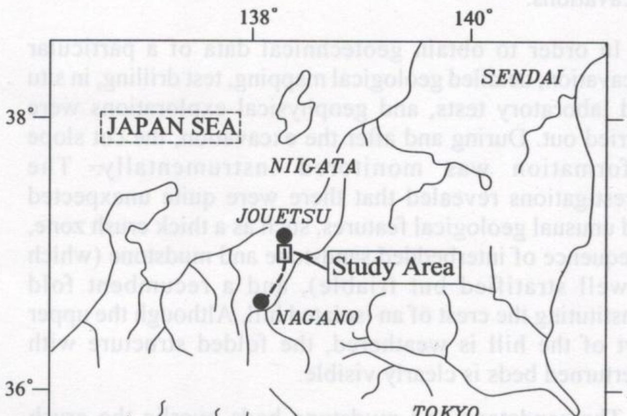


**Fig. 1: Location map of the study area and the Joushin-etsu Expressway**

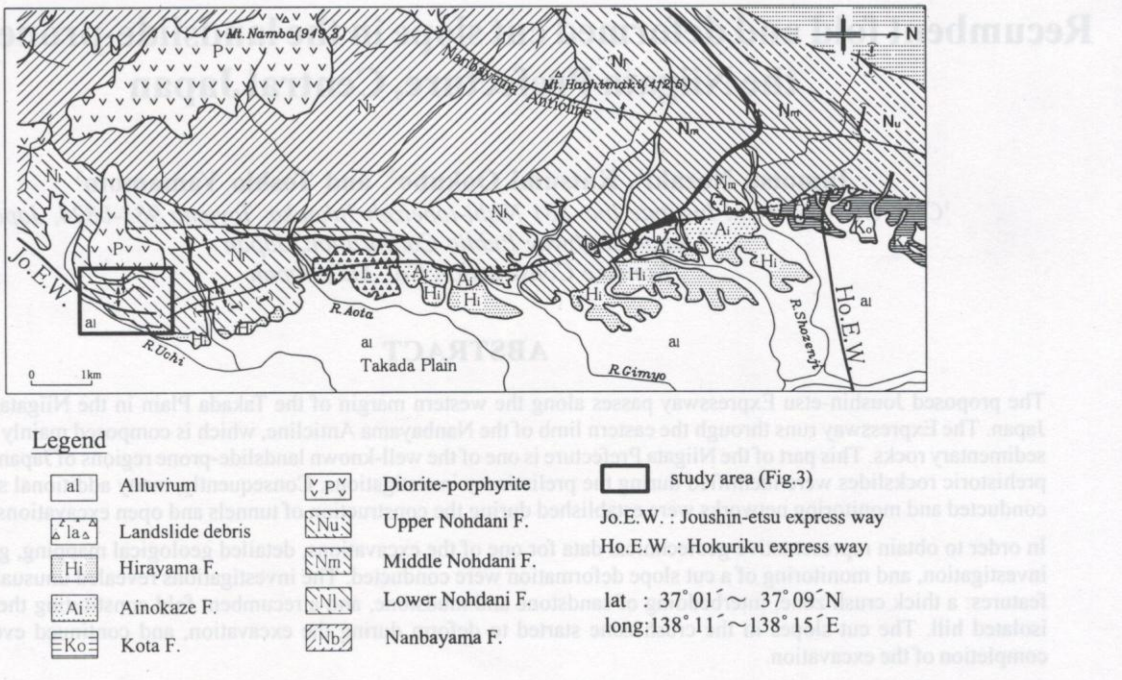


**Fig. 2: Regional geological map**

The study area was classified as one of the most landslide-prone regions of the Niigata Prefecture (The Japan Landslide Society 1988; Nozaki 1998), except for the high mountains located in the southwestern part. Therefore, many supplementary investigations were conducted and monitoring for safety measures were implemented during construction, particularly for tunnelling and open excavations.

In order to obtain geotechnical data of a particular excavation, detailed geological mapping, test drilling, in situ and laboratory tests, and geophysical explorations were carried out. During and after the excavation, the cut slope deformation was monitored instrumentally. The investigations revealed that there were quite unexpected and unusual geological features, such as a thick crush zone, a sequence of interbedded sandstone and mudstone (which is well stratified but friable), and a recumbent fold constituting the crest of an isolated hill. Although the upper part of the hill is weathered, the folded structure with overturned beds is clearly visible.

The sandstone and mudstone beds overlie the crush zone and dip 35–50° due E (towards the plain). Some signs of deformation were visible on the cut slope in the crush zone during the excavation, and they became more evident later. It is interpreted that the crush zone resulted from tectonic deformations, but the recumbent fold and the friable beds overlying the crush zone were affected by the stress release due to the stress-release induced by rapid erosion, and subsequently by gravity; therefore, this phenomenon must be a superficial valley disturbance (Hutchinson, 1991).

## GEOLOGICAL STRUCTURES REVEALED BY EXCAVATION

Many geotechnical problems, such as deformation of cut slopes and tunnels, occurred during the construction of the Joushin-etsu Expressway. Thus, a detailed geological investigation including trenching, drilling, in situ and laboratory tests, and various types of monitoring were conducted at one of the excavations located at the southern end of the project area (Fig. 2 and 3). Fig. 4 presents the geological cross-sections showing the unusual geological features: thick crush zone, recumbent fold, and stratified beds. The geological cross-sections were prepared by mapping the trench walls and using the borehole data.

The crush zone underlies the interbedded sequence of sandstone and mudstone (Fig. 5). One of the boreholes (H10-5) was drilled to about 20 m below the alluvial plain. However, it did not reach the bottom of the crush zone. The examination of cores revealed that the entire section was intensely shattered and sheared. Although the materials were the same as the overlying sandstone and mudstone, the original sedimentary structures were obliterated. The thickness of the crush zone is at least 70 m, and it is neither oxidised nor weathered except for the top 2–3 m.

The interbedded sequence consists mainly of sandstone and mudstone and there are hardly any conglomerate beds. The beds strike N10–20°E and dip 35–50° due E (to the plain). Towards the south, the beds are steeper. The sequence overlying the crush zone is highly jointed and friable. It exhibits numerous slickensides parallel to the bedding plane.

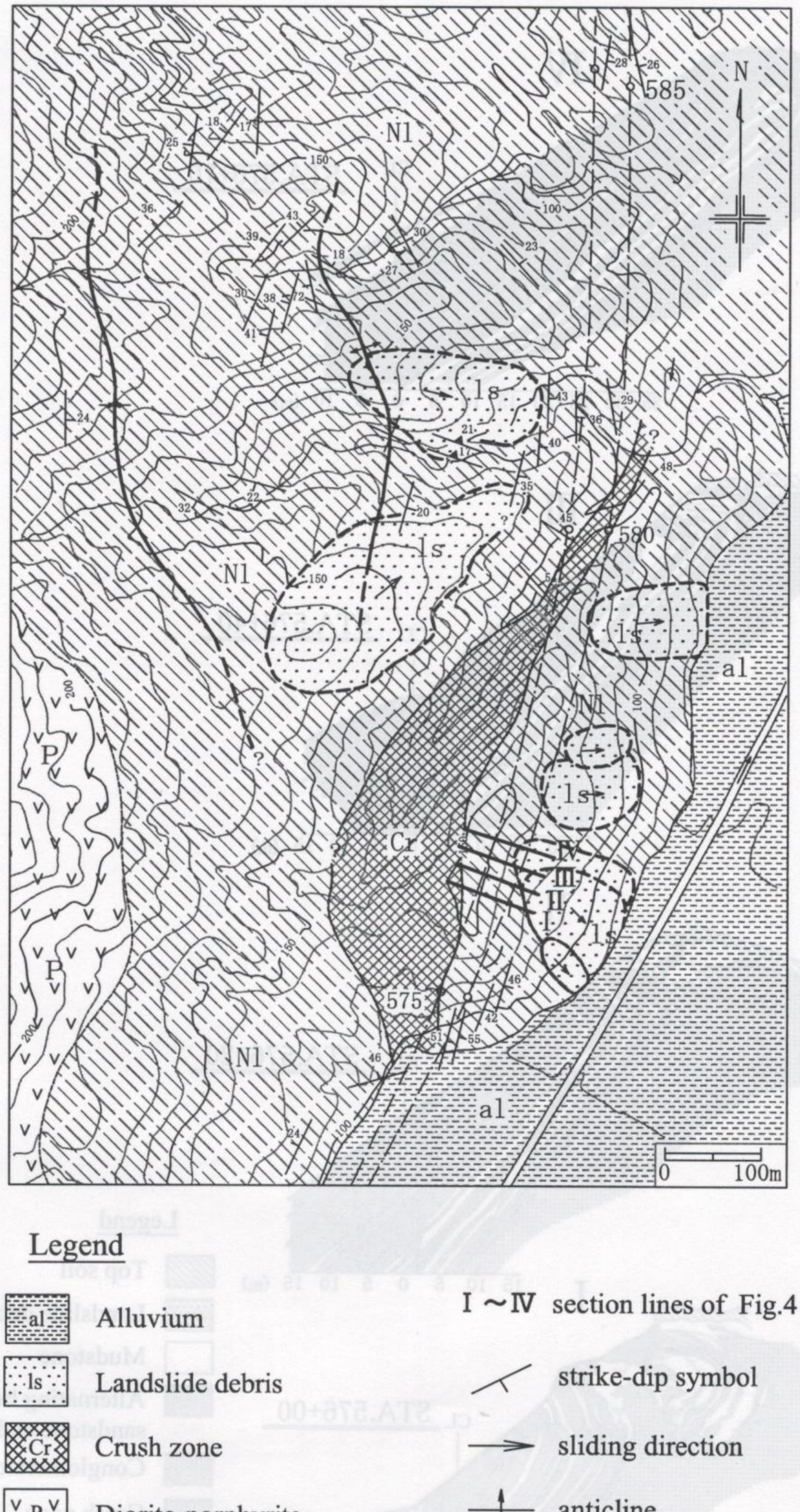


**Fig. 3: Geological map of the study area**

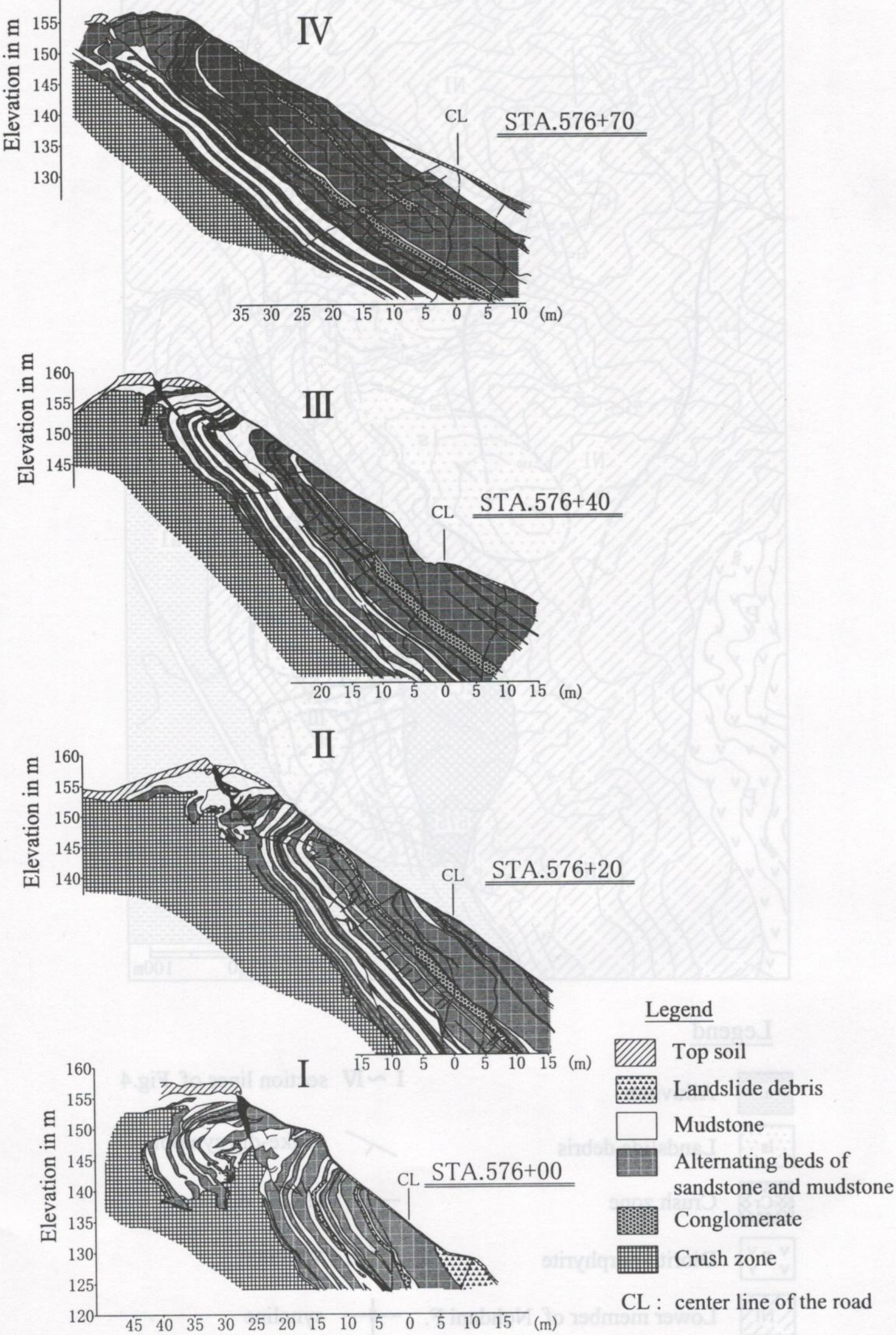


**Fig. 4: Geological cross-sections showing the detail structures of the recumbent fold**

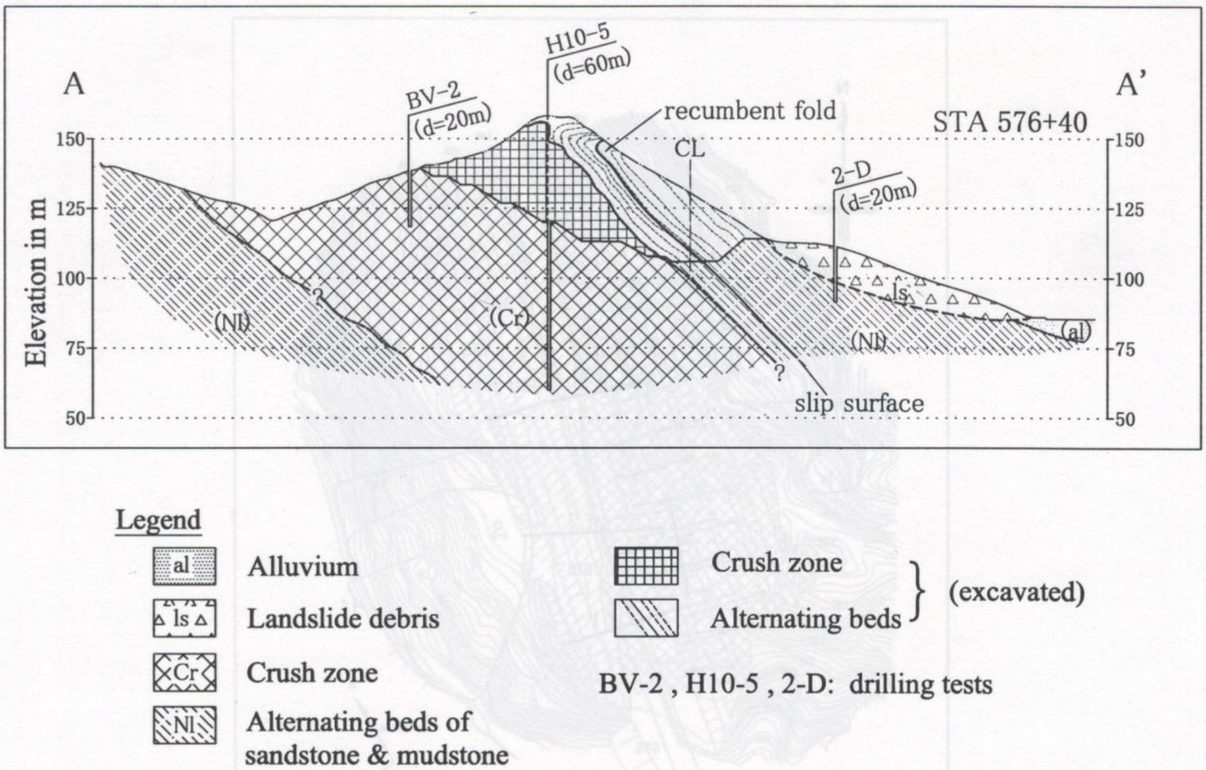


**Fig. 5: Schematic section showing the geological structure of the study area**

One of the slickensides was developed on a shear plane of a tuffaceous layer (about 30 cm or more in thickness). Due to oxidation, the layer changed its colour in a few hours after exposure to sunlight. The shear plane was traced continuously along the cut slope. It had the appearance of a slip surface of an ancient rockslide. However, the shear plane never cuts through the structure of the recumbent fold. Therefore, it is inferred that the shear planes and other slickensides are not sliding surfaces of a rockslide, but flexural-slip faults formed during folding or stress release due to erosion. Minor vertical faults cut through the beds (f1, f2, and f3 in Fig. 6).

## DEFORMATION AND MONITORING OF THE CUT SLOPE

The overturned beds were first observed in the early stage of excavation (i.e. in December 1996), and the entire structure of the recumbent fold was revealed in the next spring. Though it was noticed that the beds were intensely deformed (as indicated by chaotic clay layers at the western edge of the trenches), the magnitude of the problem was not appreciated yet. As the excavation progressed, it was clear that the cut slopes of the western hillsides were underlain entirely by the crush zone consisting of sheared and friable rocks and clay including smectite. Therefore, the cut slope surface was protected by reinforced concrete. Within a few weeks, en échelon cracks and some random cracks were observed on the benches in the new cut slopes and on the concrete slope protection structures. Eventually, the entire cut slope started to deform. Some small displacements developed along the pre-existing minor faults, which are oriented in N–S direction, and the lower portions of the cut slopes started to bulge (two of them are shown in Fig. 6).

An array of extensometers and numerous control points were immediately established on the cut slope and beyond the upper limit of the cuts. Measurements of the control points by electro-optical distance-meter were conducted continuously. Drilling was carried out, and strain-gages were installed in the boreholes in PVC pipes to monitor the subsurface deformation. In the early stages of the monitoring programme, it was interpreted that the excavation induced a landslide, because the behaviour of the slope (based on the monitoring data), was very similar to that of a landslide. However, the data showed that the upper portion of the slope was subsiding while the lower portion of the slope was uplifting. The test data obtained so far clearly indicate that it was not a landslide because there was no continuous scarp, nor were there any cracks observed in the vicinity of the contact between the creeping and stable areas. Furthermore, no large strain accumulation was observed at the specified depth of the boreholes.

Though the cut slope deformation was still going on in June 1999, it was taking place with a slower rate from the summer of 1998. The grading work (including the cut slope construction) was completed by the end of 1998. No deformation was observed on the eastern side (towards the plains) of the cut slope in the sandstone and mudstone beds.

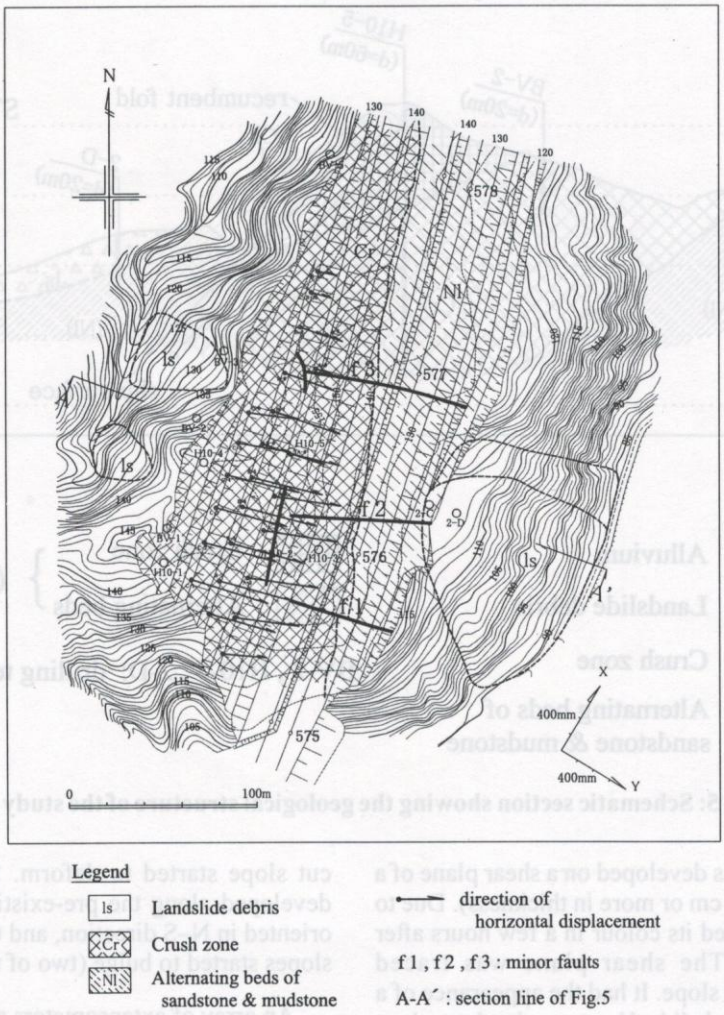


**Fig. 6: Geological structure and horizontal displacement of the cut slope**

The horizontal displacement of control points (vector in terms of X- and Y-axes) for the period of one year between May 1998 and June 1999 is shown in Fig. 6. The map shows the displacement occurred towards the downhill direction with the maximum displacement measuring up to 400 mm in a year. The horizontal displacement (Y-axis) and the vertical displacement (Z-axis) measured in the three-month period between July and October 1998 are shown in Fig. 7 and Fig. 8, respectively. Fig. 7 shows that the longer the cut slope, the larger the lateral deformation. Fig. 8 shows that the most subsided area is located beyond the upper edge of the slope, and the lower part of the slope is uplifted. It appears that the central portion of the uplifted area coincides with the former summit of the isolated hill. The mode of deformation of the cut slope clearly demonstrates that the deformation is caused by the stress release induced by unloading and subsequent gravitational displacement, and hence not by a landslide.

## DISCUSSIONS

This type of extraordinary tectonic structure has never been reported from the Neogene sedimentary formations in this region. Superficial disturbances due to the prehistoric rockslides, however, have been observed in the past (Nozaki and Fukumoto 1992). Many complicated folds, faults, and other geological features caused by the rockslides were encountered during the excavation. Thus, in the early stage, it was interpreted that these unusual structures must have been formed by a large prehistoric rockslide. As more data become available, it was clear that a deep-seated landslide could not explain the features encountered. We offer the following reasons:

(1) One of the boreholes was drilled to about 20 m below the alluvial plain, but it did not reach the bottom of the crush zone as shown in Fig. 6. Consequently, the thickness of crush zone would be far greater than 70 m.

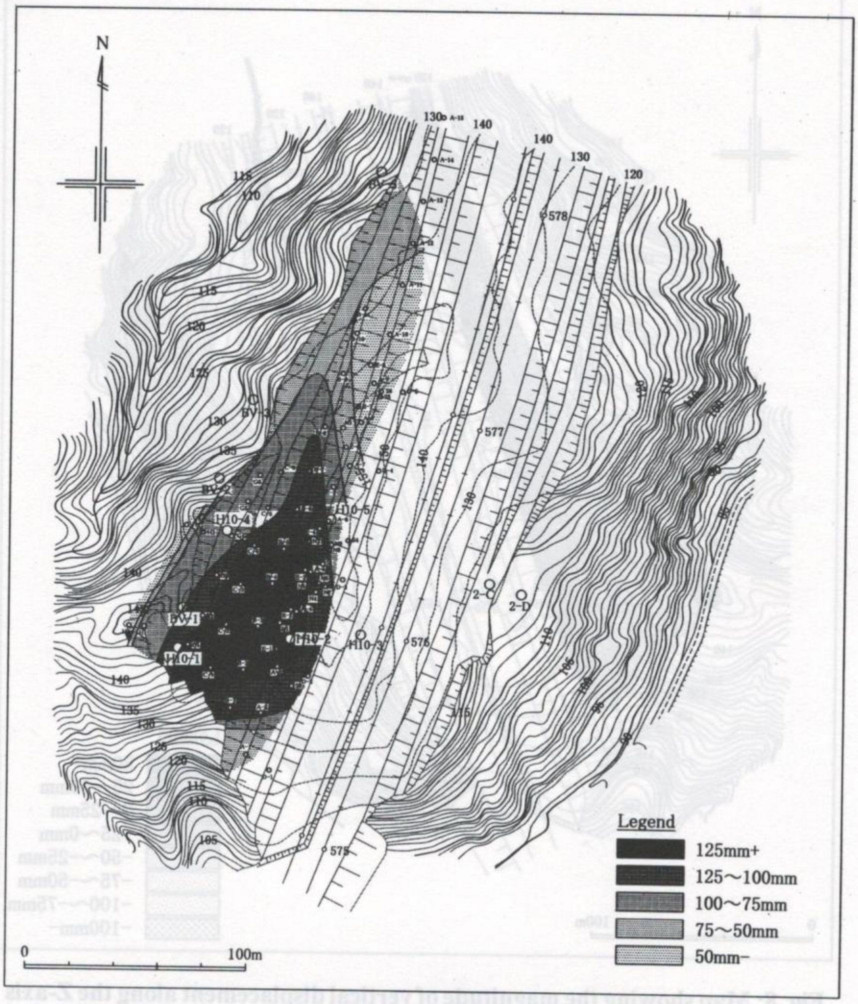


**Fig. 7: Map showing the magnitude of horizontal displacement along the Y-axis**

(2) Generally, typical rockslides are not crush or deformed in a chaotic manner as found in this case, and usually retain the original sedimentary structure except along the edges of the slides (Nozaki and Fukumoto 1992).

(3) The crush zone appears to be tight and fresh, where the overlying beds are friable and oxidised in places, and does not include any foreign materials such as soils and fragments of diorite porphyry, which are found on the upper slopes.

(4) Although there are many slip surfaces (slickensides) parallel to the bedding plane in the sandstone and mudstone, they never cut through the structure of the recumbent fold. As shown in Fig. 4, the stratification and the morphology of the fold are well preserved.

There is no concrete evidence of the mechanism that created the thick crush zone. However, it is inferred that it is related to the extensive intrusion of diorite porphyry. As shown in Fig. 3, it appears that the crush zone thickens towards the intrusive body.

Although we did not observe definite evidence to explain the mechanism of the recumbent fold and the friable sandstone and mudstone beds, we infer that it must be related to the stress release due to erosion, because the deformation of the cut slope was clearly due to the stress release induced by the excavation, as discussed above. We therefore suppose that the present topography was formed in a similar manner by the erosion of the crush zone forming a ravine that is incised between the western mountains and the isolated hill (Fig. 3 and 5). As the incision of the ravine began, the strain accumulated in the crush zone started to release, and the overlying beds started to deform, subsequently a juvenile recumbent fold and some flexural slips occurred. After that, the present morphology of the recumbent fold might have been gradually developed by gravity. The sedimentary unit that is underlain by the crush zone was probably fractured and sheared by the release of the residual tectonic stresses.

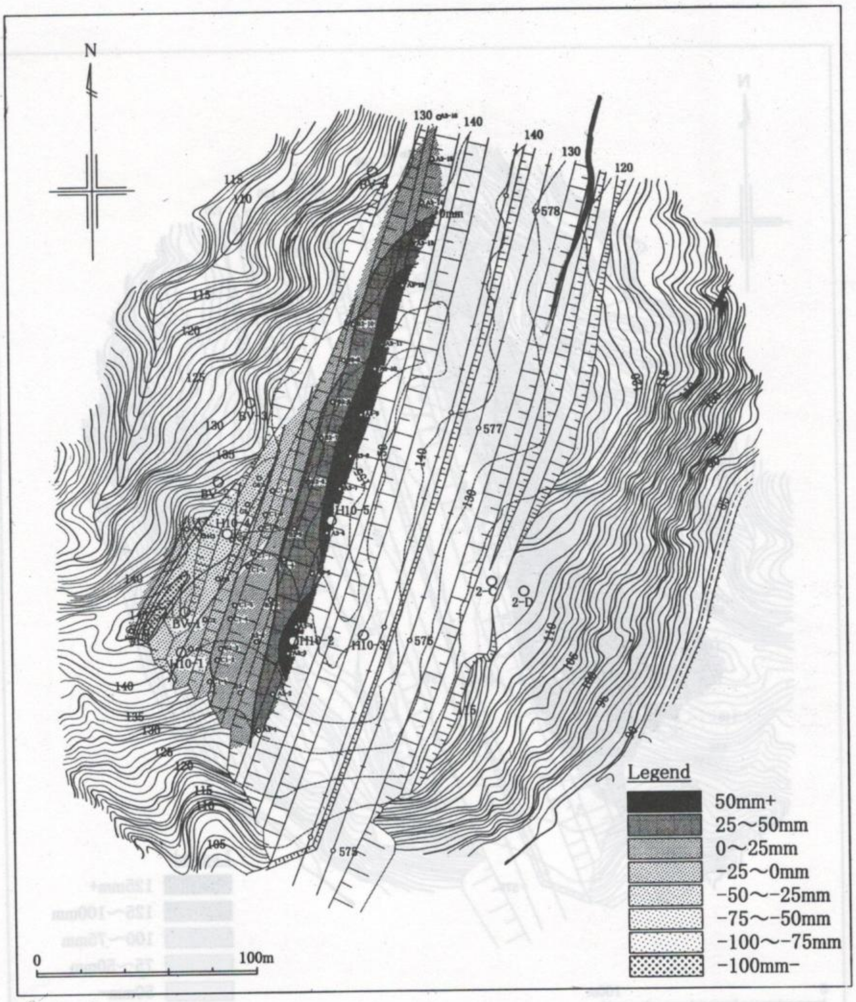


**Fig. 8: Map showing the magnitude of vertical displacement along the Z-axis**

## CONCLUSIONS

A thick crush zone and a recumbent fold were encountered during the excavation for construction of the Joushin-etsu Expressway. Although their origin and mechanisms are not clearly understood, it is inferred that the crush zone was formed by tectonic disturbances, and the recumbent fold was developed during the stress release induced by rapid erosion and subsequent gravitational pull. These anomalous features were attributed initially to the activity of a large ancient rockslide. However, the idea was abandoned because the crush zone is too extensive to be part of a rockslide. Furthermore, the bottom of the crush zone is much lower than the elevation of the alluvial plain. The morphology of the recumbent fold and the stratification of the beds underlain by the crush zone are well preserved. It is believed that the recumbent fold or flexural slips developed by stress release and gravity are the premonitory phenomena of the primary rockslide and other types of slope movement.

## ACKNOWLEDGEMENTS

We would like to gratefully acknowledge Dr. Y. Fukumoto for his advise and support in the field investigations and for his encouragement in publishing this paper. We also thank Mr. T. Seki, Mr. Y. Ogawa, and other members of the project for their assistance during the fieldwork.

## REFERENCES

Akahane, S. and Kato, H., 1989, *Geology of the Takada-Seibu district*. With Geological Sheet Map at 1:50,000, Geol. Surv. Japan, 89 p. (in Japanese with English abstract).

Hutchinson, J. N., 1991, Periglacial and slope processes. Quaternary Engineering Geology, Proceedings of the 25th Annual Publication of the Engineering Group of the Geological Society, Heriot-Watt University, Edinburgh, 10–14 September 1989, pp. 283–331.

Japan Landslide Society, 1988, Geology and Geomorphology in Landslides, Landslides in Japan, pp. 5–6.

Niigata Prefectural Government, 1989, Geological map of Niigata Prefecture and explanatory note, 128 p.

Nozaki, T., 1998, Landslides and geology. Landslides in Niigata' 98, Niigata branch of the Japan Landslide Society, pp. 3–11 (in Japanese).

Nozaki, T. and Fukumoto, Y., 1992, Mechanism of present (secondary) landslide and ancient primary landslide. Proceedings of the 31st Plenary Session of the Japan Society of Landslide, pp. 47–50 (in Japanese).