Failure phenomena and countermeasures for tunnelling in heavily squeezing mudstone

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Summary

Squeezing ground in tunnelling is associated with considerable deformations of the tunnel perimeter and face. These phenomena are accompanied by the corresponding deformation and very often the destruction of the tunnel support. Therefore, it is required for the client, designer and contractor to reduce or overcome the difficulties associated with squeezing ground by using suitable countermeasures. Heavily squeezing conditions were encountered during construction of the Nikkureyama Tunnel, in Gunma, Japan. The maximum crown settlement and convergence in the mudstone section (length approximately 380m) of the tunnel were 3,120 mm and 2,997 mm, respectively. The damage and destruction of support members were also observed occasionally. This paper summarizes the failure phenomena and countermeasures for tunnelling under such difficult conditions.

1. Introduction

The Nikkureyama Tunnel, which is 2,223m long, is part of the Joshinetsu Expressway which links Tokyo and Niigata in Japan (Fig. 1). It is a twin road tunnel with a diameter of 11m. The geology of the site mainly consists of Andesite. However, in the vicinity of the middle part of the tunnel, there was a squeezing mudstone section. In this section, the tunnel suffered from considerable crown settlement, invert settlement and convergence. The maximum initial rate of convergence was 50mm/day. Then failure phenomena such as breakdown of shotcrete lining, buckling of steel support with wing rib and cave-in from the tunnel face were observed (Fig. 2). Furthermore, the maximum rate of rapid water inflow was $3m^3$/min.

2. Geology and excavation method

Considerable deformations and serious failure phenomena were seen to occur during excavation in the mudstone section. Ongoing investigation using vertical and horizontal borings was additionally carried out (Fig. 3). Expandability index of mudstone was quite high and a large amount of water inflow suddenly occurred several times. As a result, chemical grouting and reexcavation etc. were often forced to be executed. Finally, 34 months were required to excavate this section (Fig. 4).

The support philosophy under such difficult conditions has been a heavy dispute among tunnel engineers. In this tunnel, the stiff support approach was applied. Various support sections were adopted on the basis of the geological characteristics and consideration of failure phenomena (Fig. 5). Especially in the section between Sta. 562 km 850 m and Sta. 564 km 050 m, it was extremely difficult to excavate the tunnel. In the case of section E_4, a closed ring of reinforced concrete was formed and the stiffness of the support system con-

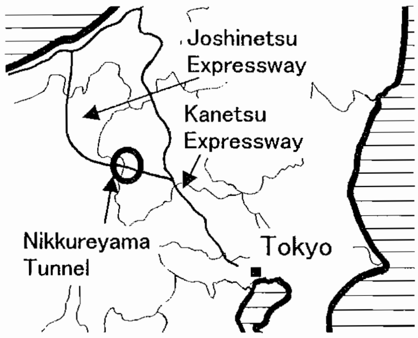

Fig. 1 – Location of Nikkureyama Tunnel.
Fig. 1 – Ubicazione del Nikkureyama Tunnel.

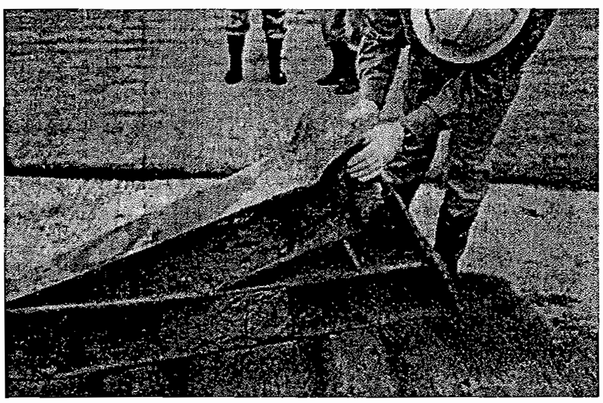

Fig. 2 – Buckling of steel support.
Fig. 2 – Snervamento delle centine metalliche.

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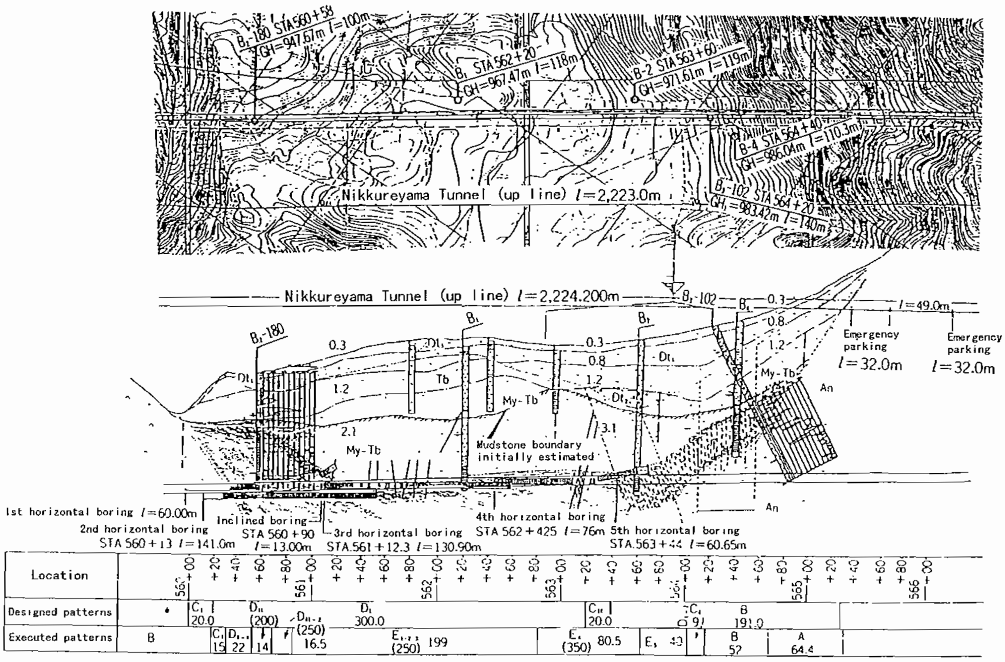

Fig. 3 – Geological conditions of Nikkureyama Tunnel.
Fig. 3 – Condizioni geologiche del Nikkureyama Tunnel.

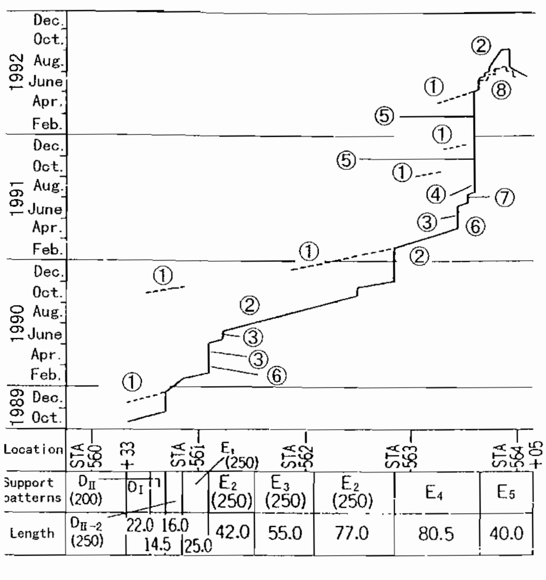

Fig. 4 – Actual progress of execution works in the mudstone section.
① Reexcavation, ② Excavation of upper section,
③ Grouting (LW), ④ Grouting (SR,LW),
⑤ Grouting (ES), ⑥ Investigation boring,
⑦ RJFP, ⑧ Pilot tunnelling.
Fig. 4 – sequenza dei lavori nel tratto in argillite.
① Nuovo scavo, ② Scavo della calotta,
③ Iniezioni (LW), ④ Iniezioni (SR,LW),
⑤ Iniezioni (ES), ⑥ Fori esplorativi,
⑦ RJFP, ⑧ Tunnel pilota.

siderably increased by casting the invert. As a result, the rate of convergence reduced, however complete stability was not achieved. According to long lasting deformations, continuous failure phenomena were observed (Fig. 6). A circular pilot tunnel was additionally required as shown in Fig. 5.

To permit casting, even though deformations were still in progress, the pressure that would develop had to be properly evaluated in the squeezing section. In order to do this, framed structure analysis was executed based on the field measurement results. As secondary lining, SFRC (steel fiber reinforced concrete) was adopted. However, the deformations did not stabilize. Countermeasures for it were also deeply considered.

Fenomeni di instabilità e interventi adottati per lo scavo di una galleria in argillite fortemente spingente

Sommario

Il comportamento spingente durante lo scavo di gallerie si manifesta con considerevoli deformazioni del cavo e del fronte. Questi fenomeni sono accompagnati da corrispondenti deformazioni dei sostegni con loro possibile collasso. È pertanto necessario per il Committente, il Progettista e l'Impresa portare sotto controllo e superare le difficoltà che si incontrano ricorrendo ad idonei interventi esecutivi. Condizioni fortemente spingenti si sono verificate durante lo scavo del Nikkureyama Tunnel, in Gunma, Giappone. Il massimo cedimento in corona e la corrispondente convergenza nel tratto di galleria in argillite (di lunghezza pari a circa 380 m) sono stati pari a 3.120 mm e 2.997 mm rispettivamente. Occasionalmente si sono verificati danni, sino al collasso degli elementi strutturali di sostegno. La nota descrive i fenomeni di instabilità osservati e gli interventi che si sono adottati in tali condizioni difficili.

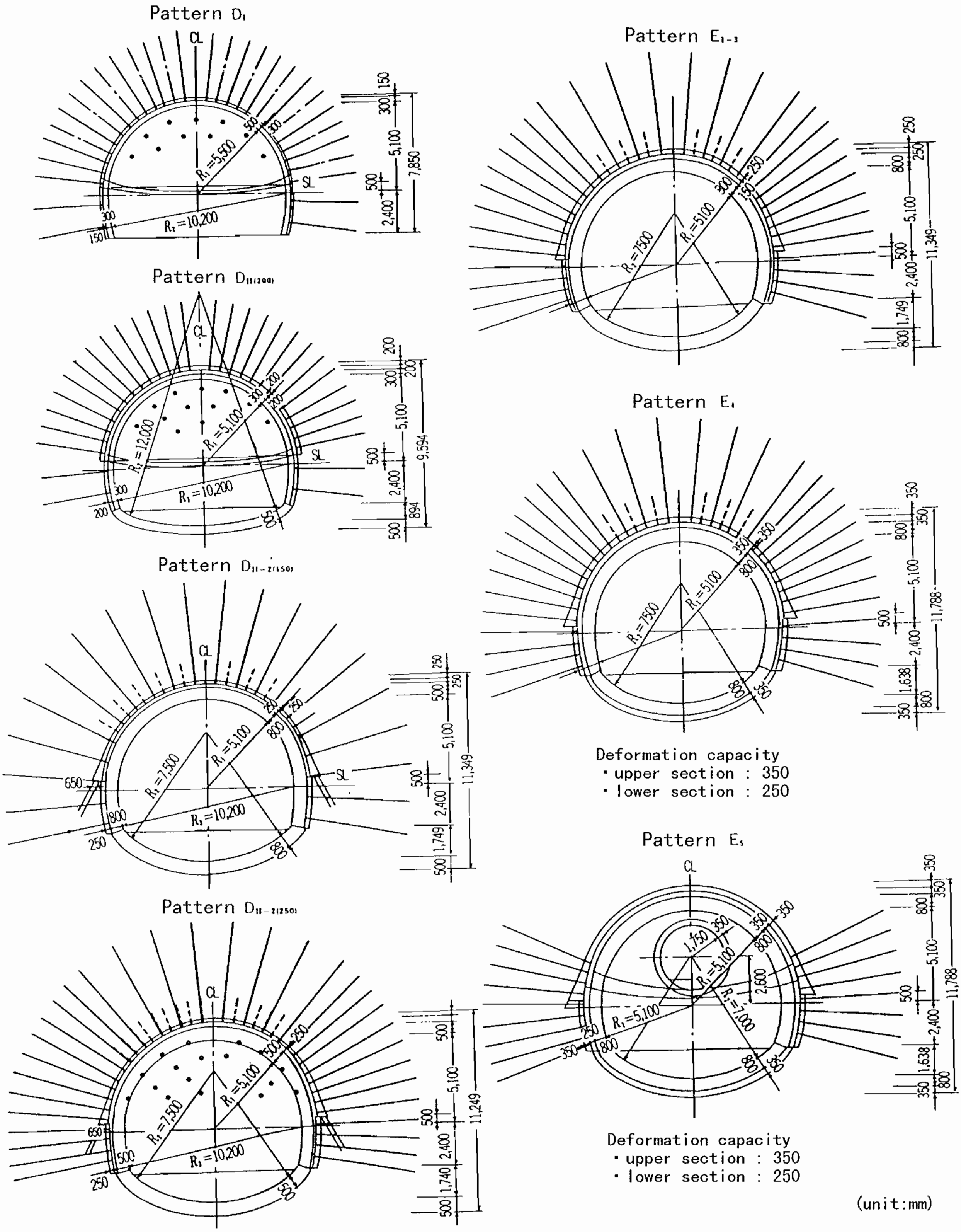

Fig. 5 – Variation of support patterns in cross section.
Fig. 5 – Variazione degli schemi di sostegno per le diverse sezioni tipo.

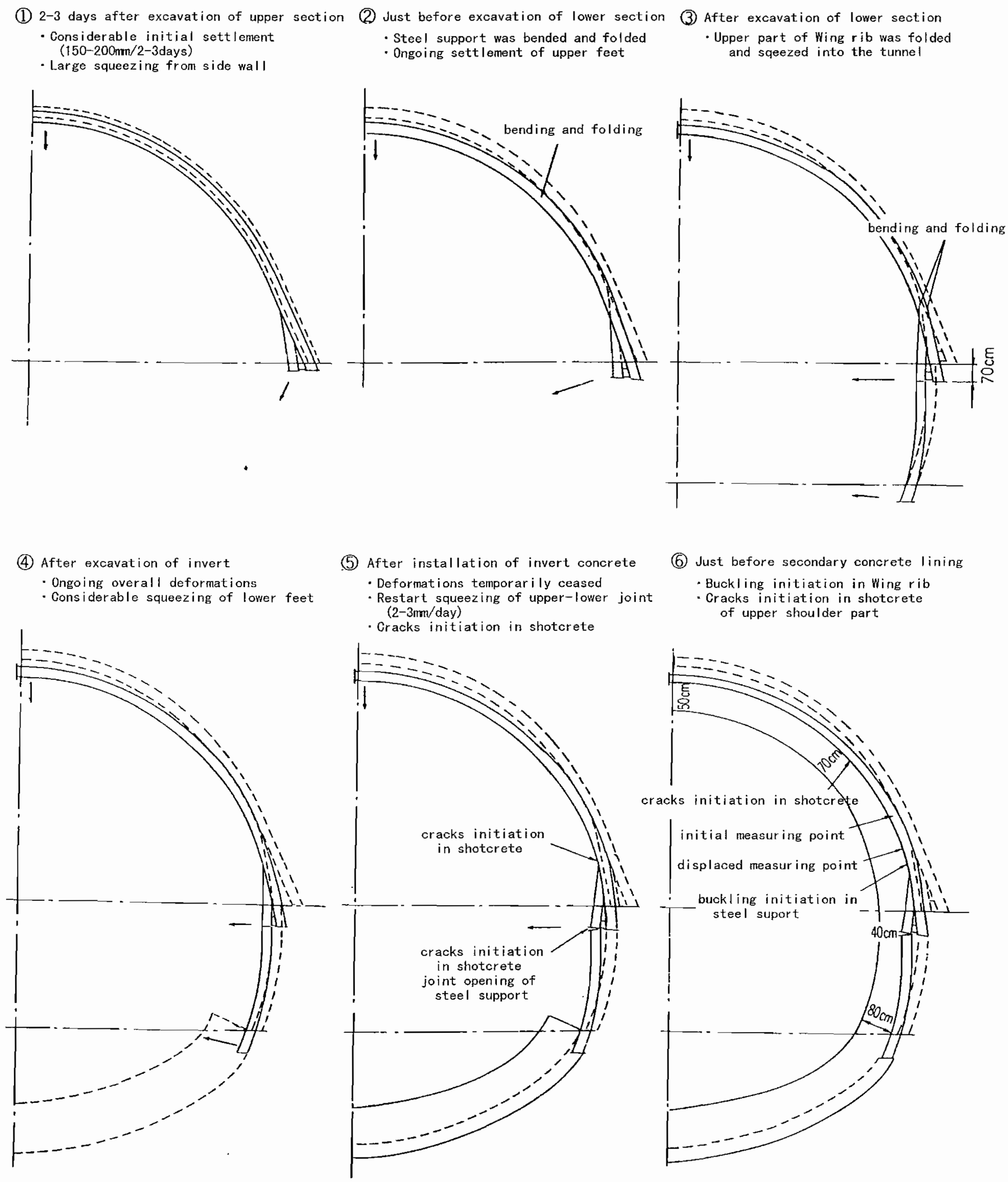

Fig. 6 – Typical ongoing failure process in relation to the construction phases.
Fig. 6 – Tipico fenomeno di instabilità nelle diverse fasi di scavo e costruzione.