Investigation of Tunnel Ceiling Collapse Accident

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Abstract

On December 2, 2012, an accident of tunnel ceiling collapse took place in the 4.4 km long Sasago Tunnel on the Central Expressway in Yamanashi Prefecture, approximately 80 km west of Tokyo, killing 9 people. The tunnel ceiling system together with adhesive anchor bolts suspending the ceiling system fell down (total weight approximately 500 ton) over a continuous road section of approximately 140 m long. Investigation and Examination Committee for this accident was established by MLIT. The committee report was released on June 18, 2013 and the present paper attempts to summarize the committee report.

Introduction

As shown in Figure 1, at about 8:03 a.m. on December 2, 2012, ceiling panels and partition walls collapsed over a continuous road section of length approximately 140 m in the east-bound lane of the 4.4 km long Sasago Tunnel. The tunnel is located about 80 km west of Tokyo and the collapse occurred at 1,150 m inside from the Tokyo-side entrance. Three vehicles were involved under the fallen ceiling panels. Two of these vehicles caught fire and burned, killing 9 people and injuring 2 people. Except for natural disasters and fires, such a severe and sudden collapse of a road structure in service has not seen before in Japan.

On December 4, 2012, two days after the accident, Investigation and Examination Committee for the Tunnel Ceiling Panel Collapse was established chaired by Dr. Toru Konda, professor emeritus of Tokyo Metropolitan University. The Committee comprised of specialists from different fields in engineering and material science and worked to figure out an understanding of the causes of the collapse and discussed technical recommendations to prevent recurrence. The Committee report was released on June 18, 2013. MLIT together with NILIM and PWRI also worked to support the Committee's investigations.

The present paper tackles to summarize the Final Report of the Investigation Committee in terms of the causes of the accident and the prevention of similar accidents. Note that most part of this paper cites from the authors' previous report (Kawahara et al. 2014).

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Overview of Sasago Tunnel

The Sasago Tunnel is operated by the Central Nippon Expressway Company Limited and it is located in Yamanashi Prefecture. It was put in service in 1977. The overall tunnel length is approximately 4.4 km. As shown in Figure 3, due to this length, a transverse ventilation system was employed and the tunnel cross section was partitioned with ceiling panels and partition walls to use the partitioned spaces as the horizontal ventilation ducts. The tunnel cross-sections are with different dimensions of L, M and S as shown in Figure 2 to meet the prescribed values for smoke and soot visibility, maximum roadway wind speed, and duct end wind speed.

The tunnel ceiling was comprised of 6m-long CT steel beams attached to the tunnel lining concrete, partition PC walls, ceiling PC panels, hanger rods, and other components, which were supported by pedestals on both sides, and hung by 16 adhesive anchor bolts in every CT steel beam (referred to below as ceiling adhesive bolts). The adhesive material used was unsaturated polyester-based resin as shown in Figure 4.

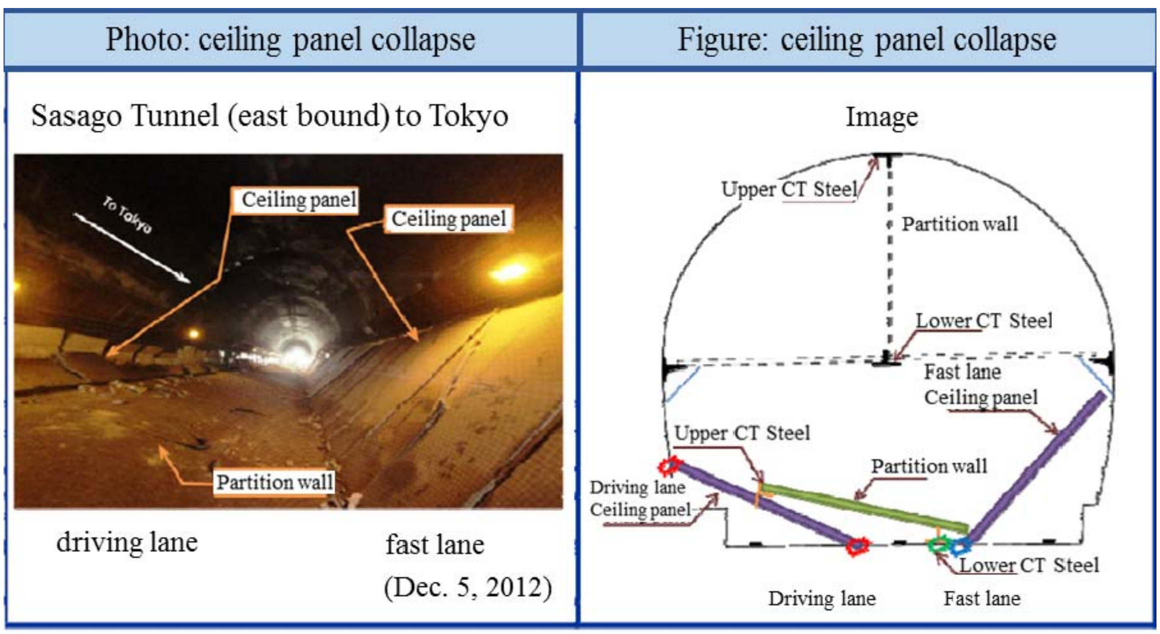


FIGURE 1   PANELS COLLAPSE

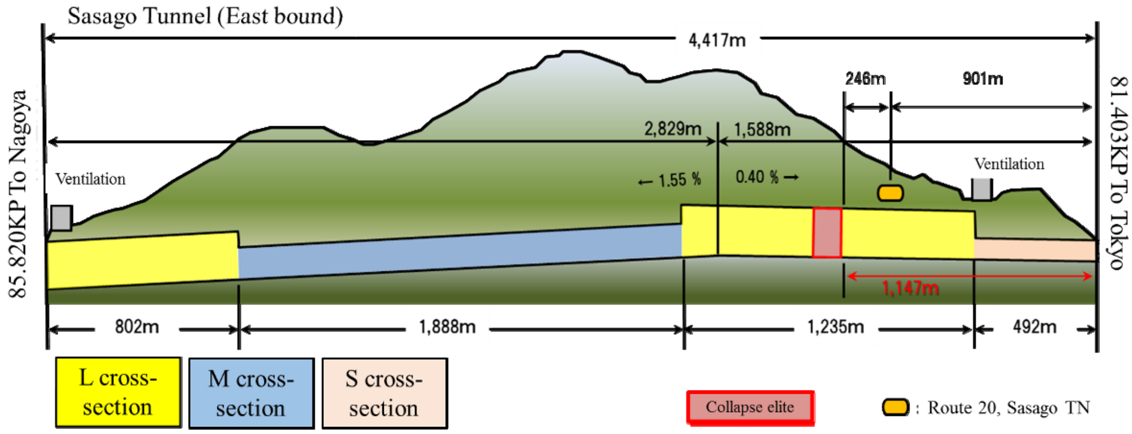


FIGURE 2 PLANVIEW OF SASAGO TUNNEL

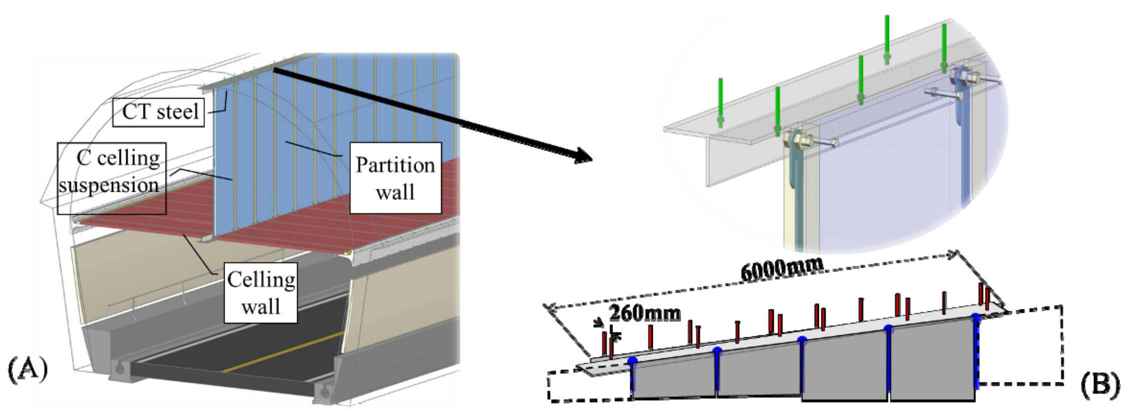


FIGURE 3 STRUCTURE OF CEILING (A) AND CT STEEL BEAMS (B)

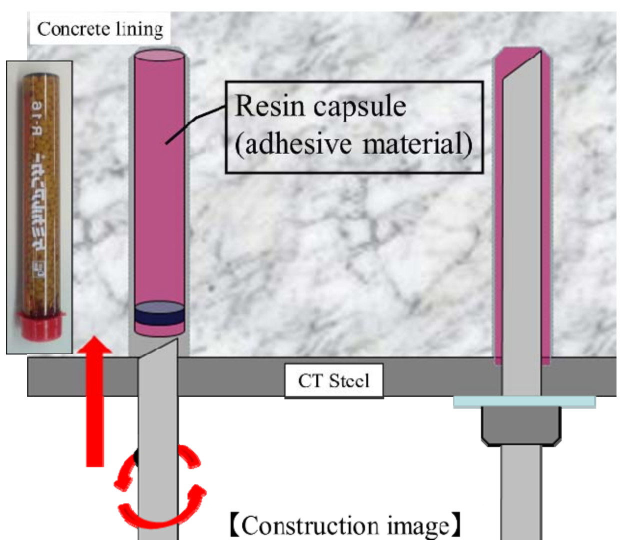


FIGURE 4 ADHESIVE ANCHOR BOLTS

Design Load Capacity of Ceiling Adhesive Bolts

Figure 5 compares the wind loads considered in the original design for obtaining the required strength of ceiling adhesive bolts to those considered by the Committee in the prediction of the order of actual reaction forces to ceiling adhesive bolts. The original design process calculated that pulling force on the ceiling adhesive bolts would be a maximum of 12.2 kN per bolt, assuming the weight of the ceiling panels, partition walls and other components, and action of a wind load in the vertical direction during operation of ventilation equipment. However, the committee pointed out that, when taking into account a lateral wind effect acting on the partition walls during the ventilation, an additional pulling force of about 8 kN per bolt was supposed to be generated, and the actual load applied was predicted as approximately 20 kN in total. This was large enough that it should have been considered in design calculation.

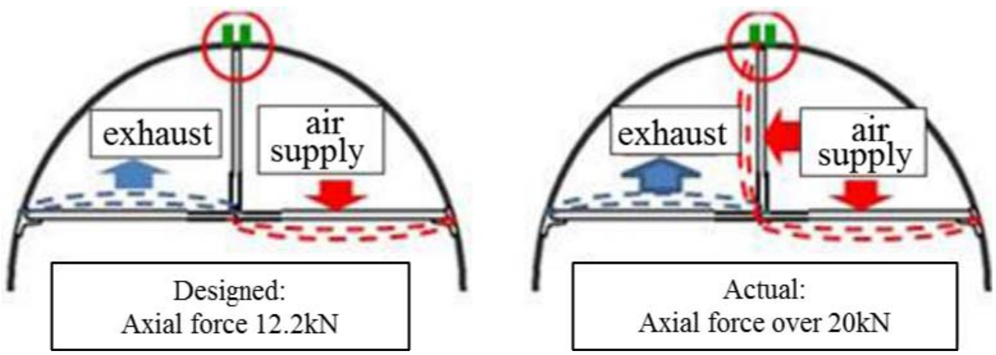


FIGURE 5 WIND LOAD OF THE DESIGN OF CEILING ADHESIVE BOLTS

Pull-Out Testing Results of Ceiling Adhesive Bolts

Pull-out load tests were run for 138 ceiling adhesive anchors that were randomly chosen at equivalent pitches in length parallel to traffic and additional 44 anchors that were chosen after the first 138 tests. Before pulling the anchors out, three inspectors were asked to conduct a series of hands-on, visual, and hammer striking inspections to judge whether or not the bolt was functional.

The observed pull-out capacity is summarized in Figure 6. The strength of Rank C is lower than a design tensile force of 12.2 kN. Rank B is between the design tensile force and the yield load of bolt material. Rank A is 40 kN or stronger. The testing found out that there were 16 bolts whose pull-out strengths were weaker than the design service load (12.2 kN, rank C in the figure), of which 14 were observed at the L dimension. Also Figure 6 shows photos of pulled-out bolts. There was a tendency that sometimes the pulled-out bolts were not fully covered with hardened adhesive layers all around.

Figure 7 compares the inspectors' assessments and the pull-out strengths. It was confirmed that a combination of hand-on, visual, and hammer striking inspections of adhesive bolts is effective for detecting malfunctioning bolts. However, the technique is also known to have technical limits, such as the difficulty of estimating pull-out strengths.

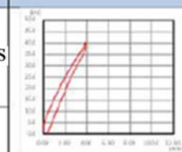
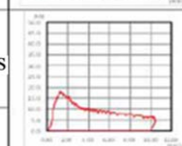
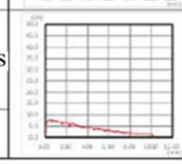
Rank of Pull-out Strength	Percentage			Typical graph of the test result	Typical picture of the test result
	Initial testing (random sampling at 138 spots)	Additional testing (44 spots)	Total (183 spots)		
Rank A 40kN or higher (9.0klbf or higher)	59 spots 42 %	11 spots 25 %	70 spots 38 %		
Rank B : Between 12.2kN and 40.0kN (2.7klbf and 9.0klbf)	72 spots 52 %	25 spots 57 %	97 spots 53 %		
Rank C Lower than 12.2kN (Lower than 2.7klbf)	8 spots 6 %	8 spots 18 %	16 spots 9 %		

FIGURE 6 PULL-OUT STRENGTH TEST RESULTS.

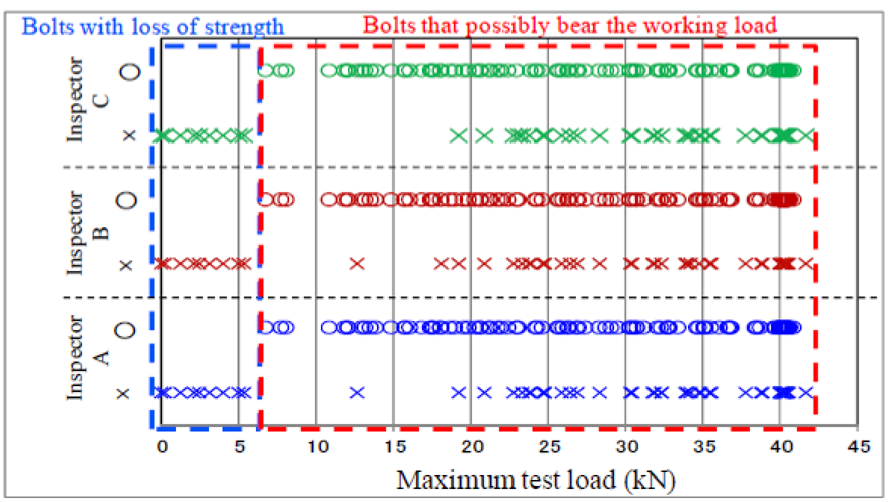


FIGURE 7 RELATIONSHIP BETWEEN HANDS-ON INSPECTION (VISUAL AND HAMMERING TEST) RESULTS AND PULL-OUT STRENGTH

<u>Installation of Ceiling Adhesive Bolts</u>

Core samples including ceiling adhesive bolts were taken from the lining concrete at the 56 bolt positions, of which 26 were taken from the accident section, and the embedding status of the ceiling adhesive bolts was checked. Figures 8 and 9 shows typical cut-out cross-sections. In a significant number of cases, the bolt tip and anchor hole bottom did not coincide, and spread adhesive, aggregate, hardener, adhesive's grass tube were left in the remaining space between the bolt tip and anchor hole base as seen near the bolt tip in Figure.8. Voids inside the lining concrete were also confirmed to be present, and in some cores, the adhesive flowed out into these voids as also shown in Figure 8.

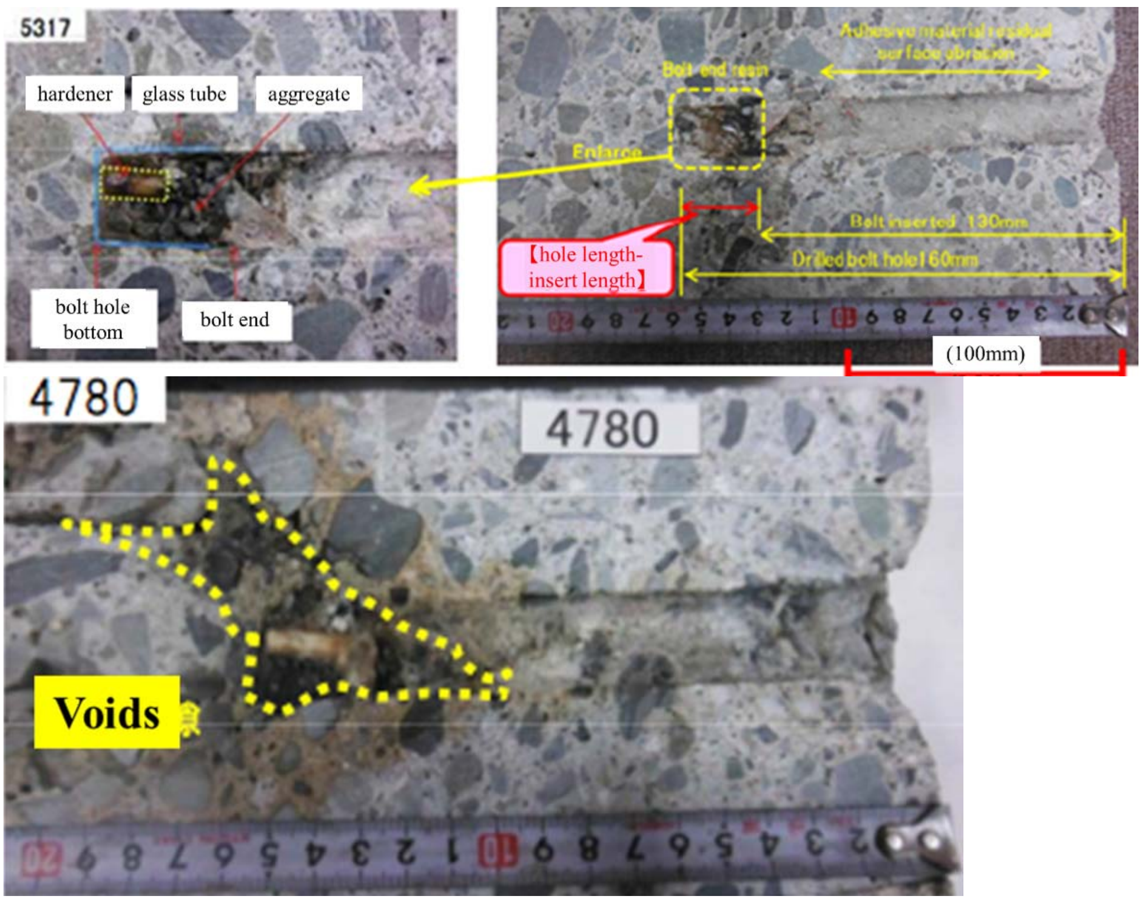


FIGURE 8 CONCRETE CORE EXAMINATION (VOIDS)

Effects Due to the Passage of Time

The remaining adhesive resin was sampled from the bolts and tested. The test proved that hydrolysis had already initiated in the adhesive resin.

In the 35 years after the tunnel went into service, the ventilation system was tuned on and off 200,000 times or more and the ceiling adhesive bolts were subjected to repeated stress amplitudes in addition to dead loads. Furthermore, the reaction forces of the ceiling adhesive bolts are assumed to have fluctuated by the winds and negative pressures every time when a large vehicle passed by.

Survey of Maintenance History for Ceiling Panel System

The Central Nippon Expressway Company had not conducted hands-on or hammer inspections of the ceiling adhesive bolts of the L cross section for 12 years. Inspections were scheduled for September of 2008 and 2012, but, due to other urgencies in inspections, hands-on and hammer inspections were postponed. Considering the result that the accident occurred, the institutions for inspections and maintenance can be regarded inadequate.

Mechanism of Ceiling Panel Collapse

Taking into account these investigation and examination results, the collapse mechanism is conjectured to be as follows.

1) With regard to the adhesive bolts hanging the ceiling system, there were underlying factors from the design and construction stage which influenced to this accident, such as the specified pull-out strengths were not always generated at the adhesive bolts even at the time construction was completed.

2) In the L cross section which was the largest cross-section, where the heaviest ceiling system was used and the largest wind loads were generated, it is believed that a decrease/loss of pull-out strength of ceiling adhesive bolts evolved due to the deterioration of adhesive resin materials and the repeated loads over many year.

3) Finally, the ceiling adhesive bolts lost a sufficient strength to suspend the ceiling panels and partition walls and the bolts were pulled out, resulting in the fall-down of the tunnel ceiling system. Because neighboring ceiling CT-beams were bridged to each other by a partition wall, the collapse occurred over a continuous section of length approximately140 m.

Committee’s Recommendations

Taking into consideration the results of the above examination, it will be necessary to promptly take safety measures such as the following for tunnel ceiling panels suspended with adhesive bolts.

1) Existing suspended ceiling panels fastened with adhesive bolts which are subjected to sustained pulling force should be removed, if possible.

2) If the bolts will be left in place, backup structures and members should be installed.

3) Until the above two measures have been completely implemented, monitoring should be enhanced, including inspection frequency.

4) Hands-on inspection (close visual inspection, hammering, and hands-on palpation) is supposed to be performed for all adhesive bolts subjected to sustained pulling force, and tensile load testing should be performed for a number of samples.

As a rule, the use of adhesive bolts should be avoided at points such as tunnel ceiling panels which are subjected to sustained pulling force, until a certain degree of knowledge has been built up regarding long-term durability performance.

Disclaimer

This report is not endorsed by Investigation and Examination Committee for the Tunnel Ceiling Panel Collapse, MLIT, or NILIM. The contents of this document reflect the author’s understanding of the report of Investigation and Examination Committee for the Tunnel Ceiling Panel Collapse.

References

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Kawahara, S., Doi, H., Shirato, M., Kajifusa, N, and Kutsukake, T. 2014. Investigation of the Tunnel Ceiling Collapse in the Central Expressway in Japan, TRB 93th Annual Meeting, Washington D.C., TRB Paper Manuscript #14-2559.