Executive Summary

At 9:30 am on October 1, 2019, Nanfangao Bridge broke and collapsed. The body of the bridge, including the deck and arch, fell into the channel of Nanfangao Fishing Harbor. A tank truck owned by CPC Corporation was passing over the bridge on its way to the Nanfangao Yuyuyuchuan Gas Station and fell together with the deck and caught fire. Three fishing boats moored under the bridge were also crushed. The collapse resulted in the deaths of six crew, with injuries sustained by nine other crew, the truck driver, and three rescue personnel.

Based on the Transportation Occurrences Investigation Act, Taiwan Transportation Safety Board (TTSB) was the independent organization in charge of investigating this occurrence. Agencies and organizations invited to participate in this investigation included the Ministry of Transportation and Communications (MOTC), Directorate General of Highways of the MOTC, Maritime Port Bureau of the MOTC, Yilan County Government, Taiwan International Ports Corporation, and MMA Group.

The Investigation Report (Draft) was completed in September, 2020. In accordance with the standard procedure, it was reviewed for the first time and amended at the 16th TTSB committee meeting on September 30, 2020. Subsequently, it was submitted to relevant agencies and organizations for further opinion. The investigation report was then passed by the 18th TTSB committee meeting on November 6, 2020. The report was released on November 25, 2020.

After investigating the overall factual data and analysis results, there are 30 findings, 6 recommendations for transportation safety improvement.

Findings Related to Probable Causes

1. The Nanfangao Bridge was located at a fishing harbor at an estuary, an area with severe salt damage and high humidity. After the bridge had been used for many years, its waterproof facilities for the stay cable system gradually deteriorated. The waterproof seam seals on the metal boxes of the divisional island and on the HDPE tube became hard and had cracked. Rain water traced the HDPE tube, leaked into the trough anchoring mechanism where it accumulated. The anchors and the steel stranded wires on the bridge end were situated in an environment with accumulated salty water, causing severe corrosion to the steel stranded wires near the surface of the accumulated water. Before the collapse, several steel stranded wires at No. 10, 11, 12, and 13 anchors on the bridge end had been corroded and broken. The effective residue cross-sectional area of the cable left was only approximately 22%–27%.

2. When the CPC tank truck passed by No. 10 cable on the bridge, the residual strength of the corroded steel stranded wires of the No. 11 cable system could not sustain the loading and broke. Subsequently, the neighboring corroded wires of No. 10 and No. 12 cable as well as No. 9 and No. 13 cable system at the bridge end broke, resulting in a chain destruction of No. 8 anchor head, No. 6 anchor head, No. 7 cable, No. 4 and No. 5 anchor head, No. 3 anchor head, No. 2 anchor head, and No. 1 anchor head.

3. When the destruction of the cable system of the bridge began, as the number of broken cables increased, the stress of the steel girder of the deck increased. By the time all cables were broken, the steel girder of the deck had been significantly damaged, resulting in the bridge breaking and collapsing.

4. The Nanfangao Bridge was a special bridge with a double-fork type single arch design. Critical loading components such as the cables and the anchorage systems were located in concealed places such as the arch, tube, or bridge steel girders. Due to the structural mechanics behavior of the bridge and the uniqueness of the components of the bridge, regular inspections for special bridges should have been implemented to verify the robustness of the bridge structure. However, before the occurrence, the attributes and statuses of bridges and regulations of the competent authorities for bridges were not comprehensive. Inspection methods and guidelines for special bridges were also not comprehensive and were not implemented solidly. Consequently, after the Nanfangao Bridge was completed, the seven bridge inspections that had been conducted were all regular visual inspections. In addition, during the 3 years and 7 months before the occurrence, no bridge inspection was conducted.

Findings Related to Risk

1. For many years, the road on which the Nanfangao Bridge was located did not belong to the highway system. Consequently, it lacked a highway competent authority as defined by the Highway Act to follow relevant bridge inspection and reinforcement regulations to conduct inspection, assessment, maintenance, and reinforcement. Nor were there special bridge inspection items or inspection methods established for the Nanfangao Bridge.

2. According to the Highway Act, the MOTC only manages the maintenance of national highways and provincial highways, not roads in harbor areas. Consequently, bridges such as the Nanfangao Bridge, though are under its system, are not included in its maintenance and management scope. (1.12.2, 2.4.1)

3. Neither the Maritime Port Bureau of the MOTC nor the Taiwan International Ports Corporation were the competent authority for the Nanfangao Bridge road as defined by the Highway Act. They did not understand the maintenance and inspection methods related to bridges. Consequently, for many years, they only conducted general inspection and maintenance tasks and did not follow relevant bridge inspection and reinforcement regulations promulgated by the MOTC to maintain and inspect the Nanfangao Bridge.

4. Before the occurrence, except for the MOTC, the bridge maintenance organizations of each department did not by themselves or refer to the highway bridge inspection and reinforcement regulations and establish special bridge inspection and maintenance operation regulations, using them to implement special bridge inspection and maintenance operations on the bridges within their jurisdiction.

5. Except for the bridges under the jurisdictional control of the MOTC or of the local government, other departments of Taiwan do not have the same regulation or

relatively comprehensive highway bridge maintenance and inspection regulations or specifications. No unified maintenance and inspection mechanism exists for all bridges in Taiwan, and this lack may place some bridges in Taiwan at risk from not being effectively inspected, assessed, maintained, and reinforced.

6. Before the incident, the MOTC had promulgated the Highway Bridge Inspection and Reinforcement Regulation as the basis for highway competent authorities to implement bridge inspection, assessment, maintenance, and reinforcement. However, that regulation focuses on the inspection and reinforcement of regular bridges. It lacks relevant regulations and guidance for the inspection and reinforcement of special bridges like the Nanfangao Bridge. As a result, special bridges require highway maintenance units and management organizations to establish inspection and maintenance regulations based on the characteristics of the bridge, onsite conditions, and maintenance conditions.

7. Most critical components of the Nanfangao Bridge were situated in arches, steel girders, or tube. External visual inspection alone is insufficient for determining whether there is any deterioration inside. The training course following the Guidelines for the Qualifications and Training of Highway Bridge Inspection Personnel of the Ministry of Transportation and Communications does not offer content related to special bridge inspection. Real bridge inspection training also does not teach trainees to enter restricted spaces, such as girders or arches, for inspection. Consequently, we cannot assure that inspectors have the ability to inspect special bridges.

8. The inspection results showed that the internal and external walls of the 13 groups of anchoring mechanisms on the deck exhibited dried water marks of different degrees. Part of the upper edge and external walls of the low-edge steel plates have dried water marks and signs of corrosion, indicating that water had accumulated within the anchoring mechanisms.

9. Material test results revealed that the components of the steel stranded wires of the stay cable system of the bridge were somewhat different, possibly because they were products from different manufacturers or from different batches, but their strength and hardness did not exhibit substantial differences. The thickness of the galvanizing layer on the surface of the steel stranded wires was uneven, which may have affected its ability to resist corrosion.

10. Tensile test results showed that among the 13 cables, except for cable No. 5, which had a lower total residual intensity of load due to corrosion, the total residual intensity of loads of the rest of the cables all exceeded the standard of 351.36 metric tons.

11. Tensile test results also showed that when the tensile load reach 262.42 and 319.88 metric tons, No. 10 and No. 11 upper anchor head broke, respectively. Their residual strength did not meet the test regulation of the Post-Tensioning Institute of the United States.

12. The anchorage system recorded in the as-built drawing of the Nanfangao Bridge differed from the actual construction not just in the omission or mis-recording of scale labels. These differences could affect the subsequent assessment, planning,

and implementation of bridge maintenance and inspection.

Other Findings

1. In the small hours on the day of the occurrence, a sensible earthquake with an earthquake intensity of 1 occurred in Taiwan and was recorded by the Suao Weather Station. During the occurrence, Nanfangao was under the influence of a typhoon and its peripheral circulation. However, these should have no impact on the bridge structure.

2. Inspection of key evidence including the main bridge arches, cables, anchorages, and deck girders, as well as subsequent key evidence inspection and testing did not uncover traits of fatigue failure.

3. The as-built drawing data shows that the U-ribs on the deck should have been welded using full penetration weld. However, on-site inspection discovered that during the actual construction, end plates were added and a fillet weld was used. Nevertheless, based on the actual damage process of the bridge, the aforementioned discrepancy between the as-built drawing and the actual construction result do not have a direction relationship with the bridge being broken.

4. The bridge pavement loading analysis result revealed that the actual mean thickness of the pavement was 12.5 cm, whereas the as-built drawing designed pavement mean thickness was 8.6 cm. Still, the maximum difference between the sling tension on actual tensile ultimate load of the two was only approximately 2.5%.

5. Material analysis results showed that the component of the anchor head of the bridge met the JIS G4051 S45C specification, with a yield strength of approximately 338 MPa and a tensile strength of approximately 674 MPa.

6. Simulation using structural analysis software revealed that under the designed vehicle load, if the cables were not corroded and the anchor head strength was as designed, the cable may allow approximately two to four strands to break. If the anchor head strength was the actual residual strength, then the cable may allow approximately one to three strands to break.

7. The structural analysis simulation also revealed that the maximum tensile force caused by the designed vehicle load is approximately 49.1% of the ultimate load. The maximum tensile force caused by vehicles carrying wave-absorbing blocks and soil are approximately 43.0% and 41.8% of the ultimate load, respectively. These simulations showed that the impact of carrying wave-absorbing blocks and soil on the cable and the steel structure did not exceed the range of the designed vehicle load.

8. Each bridge cable was covered by a HDPE tube. The anchor head was in the arch and inside the deck. The failure of the steel stranded wires and the anchor head occurred inside the structure. The bridge collapse video only shows part of the broken bridge. The actual location of failure and the sequence of the failure cannot be known.

9. Each component of the anchorage system of the Nanfangao Bridge was inspected. They were discovered to differ from the anchor head photos provided by Freyssinet in 2010 and from the product description of the 1999 version of the anchorage system of said company. Therefore, the anchorage system used in the Nanfangao Bridge might not have been constructed using the Freyssinet stay cable system recorded in the as-built drawing.

10. During the investigation of the occurrence, the investigation team requested documents related to bridge design, construction, supervision, inspection, and acceptance inspection. However, because it had been a long time, the document preservation units had destroyed the documents or the documents had been destroyed due to factors such as a fire accident. Consequently, the most critical documents, including the bridge structure calculation statement, construction program, on-site welding construction manual, material testing document, and material import declaration and inspection documents could not be obtained.

11. Before the incident, the Taiwan Bridge Management System did not have a reminder mechanism for bridges whose inspections were overdue.

12. Since November 2016, the jurisdiction authority of the Nanfangao Bridge listed in the Taiwan Bridge Management System was changed from Yilan County Government to the Taiwan International Ports Corporation. Because the Taiwan International Ports Corporation was not an object for supervision assessment or for evaluation in the Implementation Guidelines for the Supervision and Assessment and Evaluation for Bridge Maintenance and Management Operations in Taiwan, the process of supervision and assessment or evaluation operation could not be implemented to discover that the Nanfangao Bridge had not been under regular inspection according to its timetable.

13. When the Taiwan International Ports Corporation transport wave-absorbing blocks, the vehicle for carrying 40-metric-ton double T-shaped wave-absorbing blocks is a front single axle–rear single axle tractor used to connect a double axel semi-trailer. Together with the weight of the pallet truck, the total weight is 54 metric tons, which exceeds the limitation in the Road Traffic Safety Regulations. The engineering implementation unit did not follow the regulation and apply for a temporary pass from the highway regulatory agency, and it did not assess whether the vehicle overloaded with wave-absorbing blocks would affect the bridge loading.

14. After the Nanfangao Bridge collapsed, the average thickness of the road surface, as measured from a coring test, was 12.5 cm. In the past, there has only been one project related to the bridge pavement, which was the Pavement and Expansion Joints Improvement for the Nanfangao Bridge and Connecting Approach Roads in 2017. Relevant acceptance test records from that project revealed that that project did not substantially over pave the bridge. Other than that project, other projects were minor pavement mending projects, which would not affect the overall pavement thickness. However, based on the data collected by the inspection team, we cannot identify the cause as to why the overall thickness of the bridge pavement was higher than the design value.

Transportation Safety Recommendations

To all competent authorities for bridges (Freeway Bureau of the MOTC, Directorate general of Highways of the MOTC, Tourism Bureau of the MOTC, Civil Aeronautics Administration of the MOTC, Maritime and Port Bureau of the MOTC, Taoyuan International Airport Corporation Ltd., Taiwan International Ports Corporation, Ltd., Ministry of the Interior, Ministry of Education, Ministry of Economic Affairs, Ministry of Culture, Ministry of Science and Technology, Council of Agriculture of the Executive Yuan, Council of Indigenous Peoples, Veterans Affairs Council, Keelung City Government, Taipei City Government, New Taipei City Government, Taoyuan City Government, Hsinchu County Government, Hsinchu City Government, Miaoli County Government, Taichung City Government, Changhua County Government, Nantou County Government, Yunlin County Government, Chiayi County Government, Chiayi City Government, Tainan City Government, Kaohsiung City Government, Pingtung County Government, Yilan County Government, Hualien County Government, Taitung County Government, Penghu County Government, Kinmen County Government, Lianjiang County Government)

1. Rapidly follow the Guidelines for Bridge Maintenance and Management promulgated by the Executive Yuan to conduct bridge maintenance and management tasks, including bridge inspection, maintenance, reinforcement, and data establishment and release. The implementation, supervision, and assessment should be rigorous. Special bridge maintenance and management operation plans should be established for the special bridges within the jurisdiction. Bridge inspector qualification assessment mechanisms shall be established to ensure effective implementation of bridge inspection operations.

To the Ministry of Transportation and Communications

1. Count all the bridges under the jurisdiction. Include all bridges that are not categorized under the highway system and establish a maintenance mechanism.

2. Review the Guidelines for the Qualifications and Training of Highway Bridge Inspection Personnel of the Ministry of Transportation and Communications. Regarding the cultivation course content for special bridges inspection, provide bridge inspectors with appropriate methods and training for inspecting special bridges to improve their ability to inspect such structures.

To Yilan County Government

1. Continue to improve the requirement for the construction quality of public works. Strengthen the essential professional knowledge and familiarity of construction details on public works of management personnel. Ensure that the construction quality of public works meets the quality requirements of the design and relevant regulations.

2. Strengthen the file preservation and destruction mechanism. Keep up with the changes to the General Records Schedules and ensure that the documents of the departments are preserved and destroyed according to relevant regulations.

To MMA Group

1. Follow the evolution and development of the latest regulations of engineering technology to continue to strengthen the rigorousness of construction and supervision. Require construction supervision personnel to be familiar with essential professional knowledge and the construction details of the engineering projects they supervise. Ensure that the selection of engineering materials and components and the construction as well as the composition of the as-built drawing of the construction company meet relevant design requirements and construction regulations.