12 CONCLUSIONS

The investigation by the earthquake engineering sub-committee of The Japan Society of Civil Engineers (JSCE) has been undertaken between March 16 and 24, 2001. The investigation on the 2001 West India earthquake covered various aspects of the earthquake. Specifically, the geology, tectonics and seismicity of the earthquake region, characteristics of strong motion records, damage to buildings, infra structures, geotechnical structures and lifelines have been investigated in detail and the outcomes of this investigation are presented and discussed in each chapter of this report. These outcomes and conclusions are briefly described as follows:

- Although it is generally accepted that the Indian plate is stable and seismic activity take places along the plate boundaries with other plates, there are also some earthquakes within the Indian plate, which implies that the Indian plate is not perfectly rigid. The 1819 Allahbund earthquake (M8), 2001 Kutch earthquake (M7.9), 1993 Latur earthquake(M6.3), 1997 Jabalpur earthquake (M6) and 1970 Broach (M5.4) indicate that great intra-plate earthquakes may also occur in Indian plate.
- The seismic records on the previous day (January 25, 2001) obtained by the Bhuj seismological observation station during a visit on March 21, 2001 indicated that there was not any foreshock while there were numerous aftershocks following the mainshock.
- The aftershocks are scattered around the USGS epicenter and the distribution of aftershock data seems to confirm the fault plane solutions obtained by four different institutes. Since there was not any well-defined fault scarp on the ground surface, it is difficult to say which of the fault planes determined from the fault plane solutions corresponds to the causative fault. Nevertheless, the fault plane with the NE strike and dipping south could be the causative fault of this earthquake in view of the spatial distribution of the shocks and widely scattered surface ruptures.
- Widespread liquefaction was observed in the Rann of Kutch, the Little Rann of Kutch as well as the coastal areas of the Gulf in the vicinity of Ghandidam, Kandla, and between Malya and Samakhiali. Liquefaction was wide-spread particularly along the sea shore, river beds, ponds and marshland and salt playas. The liquefaction has manifested along long fissures and at many places it is of vent type. However, the structural damage due to liquefaction was quite limited in-spite of the huge scale of liquefaction.
- Most of the dams are earthen dams except a few which are stone masonary built. The dams are built for irrigational purposes. The dam failures were associated with the liquefaction of sub-soil along the old river course.

- Damage to railway tracks was observed in the form of bending and distortion of rails and tracks due to ground shaking and deformation. 20 railway stations across Kutch were damaged as a result of the earthquake. Gandhidham station was the worst-hit. Gandhidham railways station was an RC structure and some structural damage to the railway station was observed
- Most of roadways had to be re-surfaced due to extensional and bulging type cracking. Furthermore, the settlement of embankments of bridges caused differential settlement and slow down of the traffic.
- Railway bridges were almost non-damaged. The only reported damage occurred at Bridge No.48 between Kukma and Bhuj and it was restored on 3rd Feb., 2001.
- Most of the minor/major roadway and highway bridges in Kutch region were damaged. Paraphets of the minor and major bridges were totally or partially toppled or displaced in the entire region affected by the earthquake.
- The structural damage to Kandla, Navlakhi Ports was minor. No crane is toppled at the Kandla port. The Port Building on the piles near the main gate tilted with an inclination of 1-2 degree. Berths No.1 to 5 at Kandla Port have developed some structural damage. Berths No.6 to 9 are functional. Many piles supporting the docks of berths No.1 to No.5 were damaged by the strong shaking. The piles were cracked by the bending, and some concrete pieces were chipped from the pile tops.
- The 370 MW lignite (coal) burning plants located in Panandhro about 180 km northwest of the epicenter and they experienced only minor cracking while there was no damage to a coal-burning plant in Ahmedabad, 211. km east of the epicenter. The Kakrapar nuclear power plants Unit No.1 (220MW) and No.2 in Gujarata State were in operation at the time of the earthquake, which was located about 400km southeast of the epicenters.The Kakrapar nuclear power plant suffered no damaged, and it did not stop supplying power just after earthquake.
- Pylons were almost non-damaged in the earthquake area even some of them passed through the marsh lands and salt playas. but some of them passes through salt playas experienced damages
- In the Anjar 220 KV substation, the communications system and power protection system had failed when the battery rack collapsed. In the yard, all transformers derailed, some bushings were broken.
- Oil and chemical tanks were almost non-damaged. Damage to tanks mostly resulted from the settlement of foundation ground due to liquefaction.
- The stoppers or racks of the pipelines were either broken or buckled in the port area.
- Most of dwelings made of mud mortar either totally collapsed or heavily damaged.

The damage rate was quite high near the epicentral area, particularly, Bachau, Anjar, Lilpar, Chobari, Ratnal and the old city of Bhuj within the fort.

- On the other hand, if masonry buildings are constructed using mortar is lime or cement mortar, they performed much better and the total collapses were much less.
- Many modern reinforced concrete multi-storey buildings collapsed in two densely populated metropolitan cities of Ahmedabad and Gandhidham. Among the multi-storey buildings that collapsed, most had the ground storey left open for parking convenience with few or no filler walls between the columns. Most buildings with complete infills in the ground storey have withstood the earthquake without collapse.

ACKNOWLEDGEMENTS

The investigation team first of all would like to express their heartfull condolences to Indian people, in particular to those experienced this fearsome earthquake. The investigation team are thankfull to the following people and institutes:

- The Ambassador and the staff of Indian Embassy in Tokyo for their prompt response and efforts to get the necessary permissions for visiting the governmental organizations and academic institutes in India.

- Prof. Doshi of School of Architecture of Ahmedabad and his staff for providing first-hand information on the earthquake and organizing a discussion session with the Gujarat government officials involved with the rehabilation of the earthquake stricken area,

- Mr. Joti and his staff at Kandla port authority for providing information and showing damage to the port induced by the earthquake and sincere discussions on the rehabilation of the port

- Assoc. Prof. Dr. R. Sinha and his staff for sharing his information and discussions at Indian Institute of Technology at Mumbai,

- Mr. Hursh and his drivers for providing the excellent logistic support for the investigation