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# Damage to Railway Structures

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ABSTRACT: A vast amount of railway structures were seriously damaged, which includes RC frame structures supporting elevated railway tracks, RC station structures, embankments, and retaining walls. A length of underground RC box structures of subways, constructed by the cut-and-cover method, was also seriously damaged.

The total collapse of many RC frame structures (in particular RC columns) resulted in the complete close of several very important railways running in the affected areas for a long period, more than three months, because their reconstruction is considerably expensive and time-consuming. The authors consider that the shear failure of RC columns is one of the major causes for the collapse; this failure started with tension crack at an angle of about 45 degrees from the vertical, and also horizontal stir-ups; vertical (axial) main reinforcement cannot prevent the development of this tension crack in concrete, since the vertical and horizontal direction are of zero-compression and extension. The initial shear failure of concrete resulted into a total collapse of columns due to the lack of effective confinement by stir-ups located at a vertical space of as large as 30cm. Most of these RC structures were constructed 30 ~ 40 years ago following the old design code; the present code specifies higher seismic load level and a more close stir-up spacing ($12 \cdot \phi \approx 10$cm).

The effects of several types of poor construction practice and local ground conditions related to a possible very high amplification should also be considered. A large length of railway embankment exhibited a considerable amount of slumping, but no flow failure took place. The settlement of the embankment crest was very large at many places. In comparison to the RC frame structure which totally collapsed, the restoration of the embankment was completed only in a month or less. A large number of old type retaining walls (RWs), which are masonry RWs, gravity-type unreinforced RWs, and leaning-type unreinforced RWs, exhibited large displacements (tilting and sliding at the base), leading to a large settlement of the crest of the backfill (and railway tracks). Many others of them totally collapsed. Many cantilever RC RWs, which are of rather modern type but not supported by a pile foundation, also exhibited large tilting and sliding at the base. The most recently constructed RC RW (constructed about three years ago) is the one located at the site called Tanata for JR Tohkaido Line. This RW, supported by a rather dense pile foundation, exhibited a small displacement. This site is located in one of the most severely shaken areas. Adjacent to the above, a geogrid-reinforced-soil retaining wall (GRS-RW) had been constructed for a length of about 300m three years ago to support JR Tohkaido Line. The GRS-RW exhibited a small displacement similar to the RC RW described above, despite that the GRS-RW was constructed directly on the ground without the use of a pile foundation. By this very good performance of GRS-RW together with its cost-effectiveness and a relatively short construction period, many collapsed RWs of other types are being, and will be, replaced with GRS-RWs.

Perhaps due to severe shear deformation of a near-surface soft soil deposit, many central RC columns of the RC box of subways, which had not been designed to resist against large lateral load and located at a shallow depth, collapsed totally. This collapse led to the collapse of the roof of the RC box at one station, resulting in a large depression at the center of a road above it.

From a historical point of view, the damage to the RC frame structures is not straight-forward. Those constructed about 50~60 years ago, which has a larger number of columns and those of larger total horizontal cross-sectional concrete area, all survived. In contrast, many of those constricted 30~40 years ago, which had a smaller concrete horizontal area, all totally collapsed. On the other hand, old types of RWs (mainly, gravity-types) were damaged worst severely, while more modern types of RWs performed better, in particular, those constructed most later (RC RW and GRS RW).