The August 17, 1999, Kocaeli (Turkey) earthquake — lifelines and preparedness

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Abstract: In the weeks following the Kocaeli earthquake small teams of Canadian researchers had the opportunity to visit the heavily damaged regions, primarily the provinces of Koecali (Izmit) and Sakarya (Adapazari). Amongst other observations, information was gathered on the performance during the earthquake of regional lifelines. The visits by the team members were staggered between August and October, which provided the opportunity to observe the recovery and reinstatement of the systems in the short term. Performance during and post-earthquake of regional lifelines are reported in this paper. Comments are made on the state of preparedness with some suggestions for enhanced preparedness in Canada.

Key words: Turkey earthquake, highway, hospital, railway, water, search and rescue, communications.

Résumé : Dans les semaines suivant le séisme de Kocaeli, de petites équipes de chercheurs canadiens ont eu l'occasion de visiter des régions lourdement endommagées, notamment les provinces de Koecali (Izmit) et Sakarya (Adapazari). Parmi d'autres observations, de l'information a été rassemblée sur la performance des équipements régionaux de services essentiels à la vie durant le tremblement de terre. Les visites des membres des différentes équipes ont été échelonnées du mois d'août au mois d'octobre, ce qui a donné l'occasion d'observer le rétablissement et la réintégration des systèmes à court terme. La performance durant et après le séisme des équipements régionaux de services essentiels à la vie est rapportée dans cet article. Des commentaires sont faits sur l'état de préparation avec quelques suggestions pour un état de préparation amélioré au Canada.

Mots clés : séisme de la Turquie, autoroute, hôpital, chemin de fer, eau, recherche et secours, communications.

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Introduction

At approximately 3 a.m. local time on August 17, 1999, the provinces of Kocaeli and Sakaraya in northwestern Turkey were struck by a magnitude Mw 7.4 earthquake. The regions are densely populated and include the industrial heartland of Turkey. Major collapses of residential and industrial buildings occurred in the towns along the southern shore of the Sea of Marmara (Golcuk to Yalova) and in the cities of Izmit and Adapazari (Fig. 1). The official death count was 18 373 (Erdik 2000), with unofficial estimates of at least as many missing. The rapid growth in population in this region since the early 1980s had created a strong demand for housing; this resulted in a concentration of multilevel apartment buildings in the cities. Building practices and the enforcement of building regulations and controls in the regions were poor, with the consequence being a major tragedy.

The details of the seismicity and of the ground motion aspects of the Kocaeli earthquake have been reported by U.S. Geological Survey (2000). Building performance and a review of the building regulations have been addressed in a companion paper by Saatcioglu et al. (2001).

The focus of this paper is to report on the significant damage to regional lifelines (systems including highway transportation, railways, hospitals, telecommunications, water, sewer, and electrical distribution networks). In the brief duration visits in the period after the earthquake, the Canadian team did not have the opportunity to review in depth all aspects of the affected lifelines, and the observations reported in this paper should not be interpreted as a comprehensive performance assessment. The collective observations of the team nevertheless provide an insight into the vulnerability and performance of the lifeline networks and systems.

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Fig. 1. Map of affected region in northwestern Turkey.

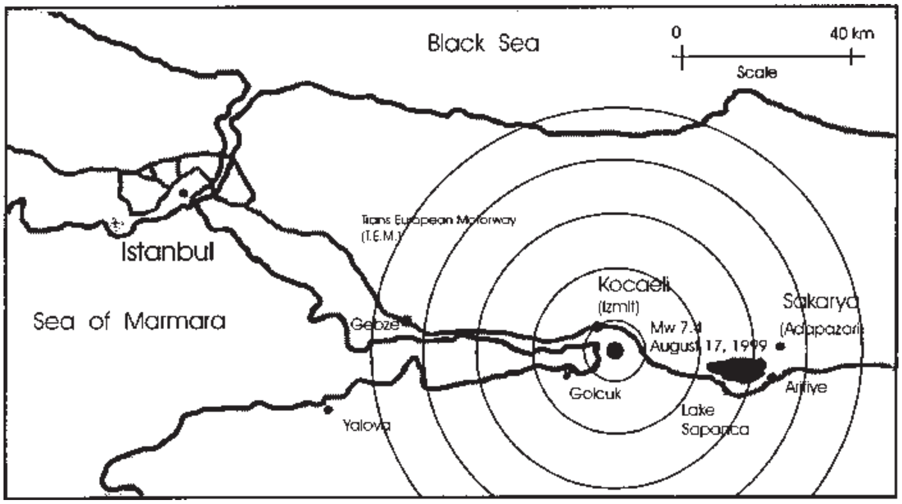

Table 1. Kocaeli earthquake preliminary damage assessment.

	Damage assessment (US$ million)*	
Sector	Lower bound	Upper bound
Housing	1100	3000
Municipal infrastructure	70	70
Environment	n.a.	n.a.
Roads, bridges, and highways	78	78
Ports	12	12
Railways, railcar factories	72	72
Telecoms	38	38
Electricity	82	82
Oil and gas (including Tupras refinery)	387	387
Enterprises	1100	2600
Education	100	100
Health	37	37
Total	3076	6

*Estimates are extremely preliminary based on incomplete data.

In a preliminary assessment report published by the World Bank (1999) an indication of the severity of the damage to lifelines can be inferred from the replacement cost estimates reproduced in Table 1.

Damage to the highway transportation network (including bridges)

The highway network system suffered surprisingly little damage given the magnitude of the observed surface faulting and the proximity of the main arteries to the epicentral region. The most important highway artery in Turkey is the Trans European Motorway (TEM) (Fig. 1), which links from Bulgaria in the east, passes through Istanbul, and terminates currently in Ankara. Eventually this will form one segment of a trans Europe–Asia network and it is an essential link for the supply of raw materials and for the distribution of manufactured goods produced in the industrial heartland of Turkey between Istanbul and Ankara. The TEM is a modern, four-lane divided toll highway.

Fig. 2. Arifiye — Unseating of bridge spans at TEM overpass.

Only one bridge collapsed during the earthquake. Located at Arifiye, this was a reinforced concrete, two-lane, four simple-span overpass bridge, spanning the TEM east of Izmit. The failure was attributed to unseating of girders, as shown in Fig. 2. The failure was a consequence of fault slip effects; there was evidence that the fault rupture passed between the reinforced earth abutment on the north side and the first support pier, almost perpendicular to the span direction. About 50 m west of the bridge a culvert passed under the highway. The fault rupture was almost parallel to the highway at this point, having just crossed the expressway lanes approximately 0.5 km west of the bridge at a shallow skew angle. The team measured a lateral offset of 3.6 m between the culvert and its associated headwall in the ditch beside the roadway and a vertical offset in excess of 1 m (Fig. 3). Failure of the seating of the first span of the bridge triggered a domino-effect collapse failure for the remaining three spans. There was damage to the reinforced earth at the north bridge abutment (Fig. 4), but the abutment performed extremely well given that it was located right atop the fault trace. There was significant ground failure in the area, including soil settlement of large areas along the tollway and on adjacent collector roads in the vicinity of the bridge (Fig. 5).

Fig. 3. Arifiye — Culvert headwall offset near overpass.

Fig. 4. Arifiye — Reinforced earth abutment at TEM overpass.

The failure of the Arifiye overpass blocked the TEM for several days until work crews could remove the debris. While the site was being cleared, the buckling and settlement induced failures in the carriageway were repaired and temporarily resurfaced so that traffic was flowing within days. Three weeks after the earthquake all traces of the five-cell reinforced concrete trapeziodal box superstructure had disappeared, as had the three piers between the spans. As well, the reinforced concrete retaining wall face of the south abutment was totally demolished.

At several of the bridges there was significant settlement in the approach fills (Fig. 6), but this was able to be reinstated, at least temporarily, in the days immediately following the earthquake. Figure 7 shows the separation of an abutment wall of a bridge that was very close to a fault rupture. Other bridges in the Kocaeli–Sakarya regions, supporting and adjacent to the TEM, showed signs of damage between the support piers, their shear keys and bearings, and the supported superstructure. The shear keys had been fractured, and the beams partially unseated from their bearings. Despite the obvious damage, the bridges remained in service with no restrictions posted.

Fig. 5. Arifiye — Fault displacement effects on adjacent collectors.

Fig. 6. Arifiye — Approach fill settlement.

Fig. 7. Arifiye — Separation of abutment wall.

Several toll-booth structures were heavily damaged, and in the period after the earthquake the Government suspended the collection of tolls. In part, this was seen as a gesture of

Fig. 8. Tepetarla — Temporary repair of railtrack after damage from fault offset.

Fig. 9. Sakaraya — Tents outside maternity hospital.

"goodwill" towards the recovery effort, but the collection system was also rendered inoperable.

In spite of the heavy damage sustained in the area, many highway bridges built on firm soil, including a large number of modern highway viaducts, survived the earthquake without any damage. According to reported information, the overpasses and spans supporting the TEM were designed to modified AASHTO specifications.

Despite the modest damage, in the days immediately after the earthquake, the TEM and the parallel old highway did not cope well with the increased traffic, and there were reports of massive traffic jams. Emergency crew access was hindered by the many private vehicles traveling from Istanbul and Ankara into the area — people concerned about relatives and friends, volunteer assistance, and sightseers. In some areas local people took it upon themselves to police the access and to open up sectors for emergency crew use only.

Damage to railways

An electrified railway track ran parallel to the TEM south of Sapanca Lake, and there was damage to the track between Izmit and Arifiye a distance of 35 km. The track was located in the area of observed surface faulting, and the faulting crossed the tracks in several locations, causing extreme distortions in the rails at these points. Figure 8 shows the repaired track near Tepetarla station where the fault crossed almost at right-angles to the rail. The offset could be measured in the abandoned damaged rails and was found to be in excess of 2 m over a length of 6 m of rail. The railway did not operate for 3 days following the earthquake, but this was due to the lack of electrical power and controls. Three weeks after the earthquake, the track was open to traffic, but trains were running at reduced speed with flagmen controlling their progress at locations of concentrated damage.

Fig. 10. Sakaraya — Maternity hospital gable-end.

Damage to hospitals

In the heavily devastated city of Adapazari, Israeli and Egyptian forces established trauma field hospitals in soccer stadiums within the city in the days following the earthquake. The Canadian Forces DART team established a primary care hospital in a soccer stadium in Serdivan (Adapazari). A 22-member U.S. military crisis response medical team provided assistance in Izmit. U.S. naval ships provided medical support in Golcuk.

Professor Mustafa Erdik of the Kandilli Observatory provided a briefing session to some members of the Canadian reconnaissance team on September 13. According to his information, one private hospital collapsed in Adapazari, but most survived the shaking well. Hospitals were designed with an importance factor of 1.5 and survived the shaking with some damage, typically non-structural. People, however, were frightened to use them and preferred to be located in tents outside (Fig. 9). One hospital was inspected in Adapazari and appeared to be in sound shape. An infill gable end wall was lost at roof level (Fig. 10), and there was movement across seismic separation joints in the hallways. Mechanical and electrical systems appeared to be undamaged. Staff reported that the facility was unused 3 weeks after the earthquake because it had yet to be inspected by the authorities and declared habitable. It appeared that there was not a strong desire on the part of the injured to be housed inside a large structure, and this was a significant component of the post-earthquake trauma. A similar observation was made at manufacturing facilities; minor damage had been repaired and factories were ready to return to production, but the workers needed to be convinced that it was safe enough to venture inside a building. This psychological resistance was not readily overcome. In one instance, a tire factory in Izmit, which suffered only minor damage from the earthquake, attempted to resume production a matter of hours before the strongest aftershock (Magnitude Mw 5.8) recorded on Monday September 13, 1999. No significant damage was

Fig. 11. Izmit — Kocaeli University Hospital: (*a*) elevation view of damaged nine-storey wing; (*b*) shear failure of 450 × 1350 mm “short columns”; (*c*) shear cracking of shear wall; (*d*) structural and non-structural damage to partition walls.

caused by the aftershock, but it was some days before the labour force was prepared to resume manufacturing operations. During this period the company had to offer counseling to the employees and report in detail on the remedial and retrofit works carried out since the initial earthquake. The visit by the reconnaissance team was welcomed by the company as a demonstration to the employees that the company was prepared to be reviewed and to receive advice from an independent engineering team.

Istanbul hospitals were able to cope; the casualty pattern did not follow the pattern of past earthquakes. For planning scenarios, the expectation was that for every person killed, five more would be seriously injured. In the Kocaeli earthquake, the ratio was closer to one-to-one, and as a consequence the hospitals were not overwhelmed. The change in the statistics ratio reflects the consequences of total building collapses and the low chance of survival for occupants.

Figure 11 shows a severely damaged wing of the Kocaeli University Hospital in Izmit. This nine-storey wing is a reinforced concrete wall-frame structure. Figure 11*a* shows the elevation view of the damaged wing, and Fig. 11*b* shows the shear failure of one of the 450 by 1350 mm columns. The presence of the deep spandrel beams created “short columns,” with shear failure occurring through the 450-mm column width. The column was reinforced with deformed 25-mm-diameter vertical bars and 10-mm-diameter plain ties at a spacing of 100 mm, anchored with 60-mm-long hooks with 90° bend. The shear failures occurred to two adjacent columns that were located in the region of a two-storey mechanical room, which created a vertical irregularity in this region of the wing. Figure 11*c* shows the shear cracking and spalling of the cover concrete in one of the interior shear walls around a staircase. This large wing of the hospital had to be closed after the earthquake due to severe structural and non-structural damage (Fig. 11*d*).

Figure 12*a* shows an overall view of the SSK Hospital in Izmit, which suffered severe damage to the three-storey older wing built in 1946. This wing is a frame-wall structure with masonry infills. Figure 12*b* shows the shear failure of a lightly reinforced concrete wall at the ground level. Due to severe structural and non-structural damage (see Fig. 12*b*) the hospital was closed. The large permanent drifts of the partition walls are evident in Fig. 12*c*. Although the newer seven-storey wing, built in 1976, was undamaged and remained fully operational, the single storey connecting structure (see Figs. 12*a* and 12*b*) suffered damage due to pounding between the connecting structure and the older wing. This pounding probably augmented the damage to the older wing.

Figure 13*a* shows the construction of a six-storey hospital near Yalova. The reinforcement details for the frame-wall structure are shown in Figs. 13*b* and 13*c*. The shear walls

Fig. 12. Izmit — SSK Hospital: (*a*) general view, 1946 wing (left) and 1976 wing (right); (*b*) shear failure of lightly reinforced concrete wall; (*c*) severe damage to partition walls.

had very good details with closely spaced confinement reinforcement in the end regions of the walls where the vertical reinforcement was concentrated. The 600 by 600 mm columns were reinforced with 12–20-mm diameter vertical bars and were confined with 9-mm-diameter ties at a spacing of 100 mm. In terms of possible deficiencies of the detailing provided, it is noted that the ties had only 90° bend anchorages with free end extensions of 120 mm, and in both the columns and the walls all vertical reinforcement was spliced at the floor levels.

Water supply and treatment

In the heavily damaged areas around the Gulf of Izmit and the city of Adapazari to the east, water supply within the towns was lost immediately following the earthquake. There were three sources for potable water supplying the regions: (1) the Gokce Reservoir near Yalova, serving people in 13 cities from Yalova to Golcuk, (2) the Kullar Reservoir in the Izmit Water Project, serving 19 cities from Golcuk to Gebze, and (3) Sapanca Lake serving the Adapazari area.

There was no significant damage reported to the reservoirs, pumping stations, or treatment facilities, but, in the short term, they all lost power for the pumping/treatment stations, and the main feed system had pipe breakages, particularly where the pipes crossed fault traces. The internal distribution networks within the cities had extensive damage from ground ruptures and from the consequences of liquefaction and settlements.

The Canadian Forces Disaster Assistance Team (DART) played a key role in the post-disaster reinstatement of a potable water supply system in the Sakaraya (Adapazari) region. The DART advance team was in Istanbul 2 days after the earthquake, and the main contingent began arriving on August 22. The unit established a base in the grounds of a soccer stadium in Serdivan (Fig. 14). The team undertook three primary objectives: (1) to establish a primary medical care (non-trauma) facility under canvas in the stadium, (2) to construct semi-permanent serviced tent accommodations adjacent to the stadium, and 3) to reinstate a potable water supply to Adapazari, in particular to the Serdivan area. Information from the DART team permitted a detailed understanding of the effect of the earthquake on the Serdivan water supply and distribution infrastructure.

Prior to the earthquake, water for Adapazari was drawn from Lake Sapanca, approximately 5 km to the west, via a pumping station located at Esentepe in the hills above the Lake. Chlorine in gas form was added to the water at the Esentepe pumping station, and gravity feed carried the water via two steel pipes: one1200-mm-diameter pipe to the modern water treatment plant located at Maltepe in Adapazari District, and the second, 700 mm in diameter, bypassing the plant to supply directly the urban pipe network for some suburbs, including Serdivan.

Immediately following the earthquake, power to the pumping and treatment stations was lost. There were several breaks in the two feeder pipes and extensive damage to the distribution network within the District. By the time power was restored, the major breakages in the feeder pipes had

Fig. 13. Yalova — Six-storey hospital under construction: (*a*) overall view; (*b*) shear wall reinforcement; (*c*) confinement reinforcement at ends of walls.

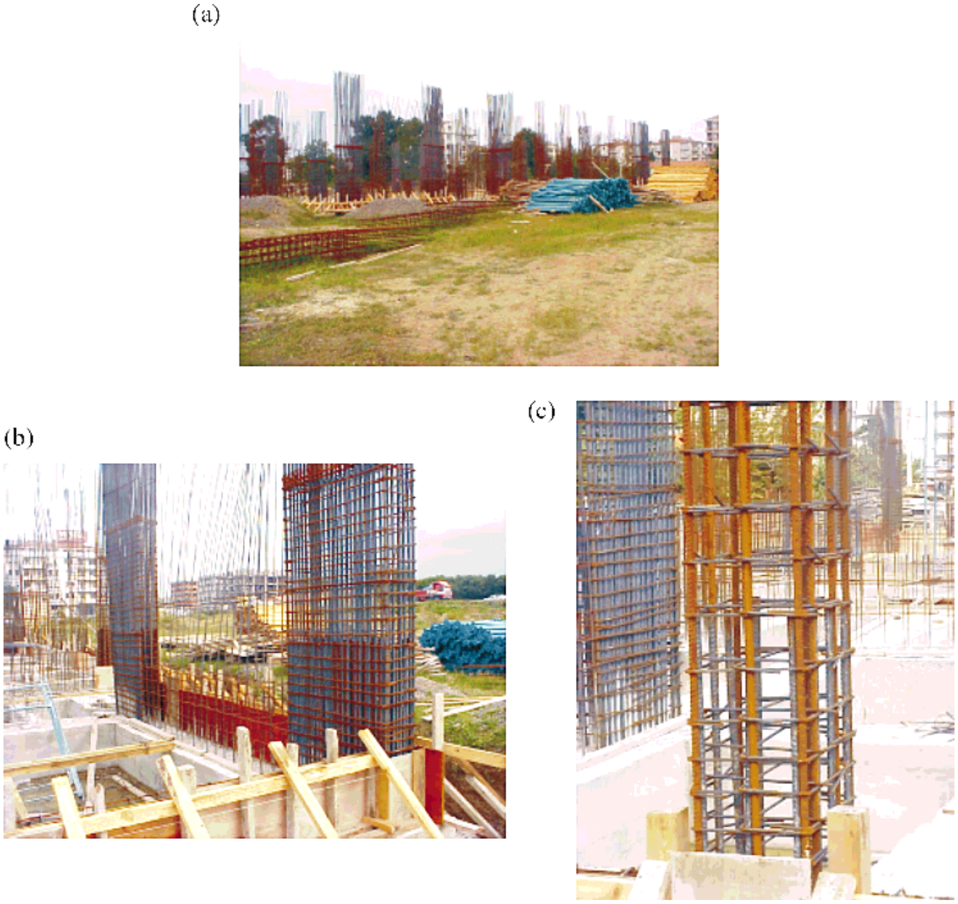

Fig. 14. Serdivan — Canadian Forces (DART) base.

Fig. 15. Esentepe — Pumping station chlorination unit.

been repaired with water supplied to the Maltepe treatment station on the fifth day after the earthquake.

One of the two intake pipes in Lake Sapanca was still out of service at the time of the reconnaissance visit, 29 days after the earthquake. The Esentepe pumping station had no major mechanical failures. However, the restraining bar supporting the chlorine gas cylinders had failed and the cylinders had overturned, leading to a chlorine gas escape (Fig. 15). Prior to the earthquake, the only chlorination of the potable water was at the Esentepe station, and the dosage was set each day as a result of a telephone call from the Ministry of Health official who took water samples in Adapazari. The Ministry was not operational after the earthquake, with the result that no chlorine was added to the water for several weeks following the event. The DART team then reverse engineered the system and identified the critical step in the supply system.

The Maltepe treatment facility, built in 1997, comprises a bank of 36 Culligan pressure feed filtration tanks each of 3000-L capacity. Ten pumps powered by 77-kW motors pro-

Fig. 16. Serdivan — 15 000-L rubber bladder temporary water reservoir.

vide the water feed. The Culligan Company inspected the station immediately following the earthquake and reported no significant damage; only one 1 in. (25.4 mm) diameter steel water pipe had fractured.

To reinstate a temporary potable water supply immediately following the earthquake, the DART team commissioned three portable reverse osmosis filtration units, locating two by the lake and the third near the camp. Temporary rubber bladder style reservoirs, each 15 000-L capacity, were placed at key locations in Serdivan (Fig. 16). Water distribution to the reservoirs continued to be a problem. Local tanker trucks were not up to the sanitation standards for potable water distribution and other trucks were on temporary secondment from Istanbul or Ankara. Fortunately, the DART team had the facility to bag water in pouches (similar to the 1.3-L milk pouches used in some parts of Canada) and these could be stacked in the back of dump trucks or trailers for distribution.

Shortly after the earthquake, the authorities feared an outbreak of disease from the contaminated water supply. Prior to the earthquake, the people did not trust the water quality and were in the habit of drinking bottled water sourced from springs in the hills. Although the bottled water did not meet acceptable potable water standards, according to the testing performed by the DART team, nevertheless this lifestyle habit contributed towards stemming any disease outbreak.

Approximately 1 month after the earthquake, the Maltepe treatment facility was running at 65–70% of capacity, and a satisfactory chlorine residual had been achieved. With a potential capacity of 100 000 t per day, the plant can easily supply the whole district. The water was being supplied to a central distribution facility below the town, where the tanker trucks could refill, and was being piped to some reservoirs. The heavily damaged north-eastern sector is expected to have to rely on temporary distribution points for some time.

Reconstruction of the urban distribution networks will involve substantial capital investment and significant time. At the time of the reconnaissance visits there was discussion about the wholesale relocation of heavily damaged cities to new sites with more stable foundation conditions. Obviously any permanent distribution system reconstruction would be premature until new town planning and land zoning strategies are resolved. In some areas, temporary mains had been laid at street level, but there was concern about their vulnerability during sub-zero winter conditions.

Communications

Telephone service suffered little interruption from the earthquake. Lack of power in the days immediately following the earthquake did limit communications; however, there is widespread use of cellular telephones and this service was quickly functioning. There were extreme demands placed on the system both internally, and for international calls, given the immensity of the disaster. The reduced performance was not as much a consequence of earthquake damage, rather the inability of the network to service such a peak demand on the resources. In the period following the earthquake (still in place a month after the event) internal charges for cell phone calls were suspended.

Search and rescue

The search and rescue coordination, particularly for the placement of foreign rescue teams and aid resources, was undertaken by a United Nations task group (United Nations' Office for the Coordination of Humanitarian Assistance – On-site Operations Co-ordination Centre (UNOCHA-OSOCC)) in combination with Turkish authorities. The terminal building and hangars at the Istanbul international airport served as the command post. In the critical hours immediately following the earthquake there was difficulty in getting the emergency personnel into the areas, particularly when, as reported earlier in the paper, the highway transportation network became locked.

Press reports were very critical of the slow response by the Turkish military; however, the military lost key personnel in the building collapses in Golcuk. There were challenging logistics in the vital early days following the earthquake — seemingly simple problems as securing aviation fuel supplies for helicopters and diesel fuel for heavy transporters and machinery. Helicopters lost precious hours of flight time when airport fuel supplies could not be accessed immediately.

Interviews with Turkish volunteers, acting as translators, assigned to foreign rescue teams highlighted coordination problems between rescue teams. There did not appear to be an internationally recognised system for marking buildings that had been searched. As a consequence, time was wasted when a second team repeated the search of the same building, yet other areas were desperate to have the resources of a rescue team. Highly trained teams would pass over a site and identify where their animals or equipment had located signs of trapped survivors, but not always did a rescue team follow behind.

Much of the initial response relied on the initiatives of the immediate neighbours. Younger people, in particular, took a lead in opening the highway arterials for emergency traffic, in directing site search and rescue activities, and in coordinating the distribution of food and clothing aid.

A potential weakness in disaster response planning was highlighted when key coordination personnel were themselves affected by the disaster. In some cases, injuries to themselves or to immediate family prevented immediate par-

Fig. 17. Serdivan — Tent camp constructed by Canadian Forces DART team.

Fig. 18. Serdivan — Prefabricated "temporary" housing under construction.

ticipation in the disaster response. There is a potential lesson for Canadian emergency response controllers. Cities in Canada have disaster response plans and at times test these plans with scenario exercises. How often are these plans tested in the absence of key personnel — and what is the level of redundancy incorporated into such planning, recognising that particular people may not be available? Successful rescue of trapped and injured people requires an immediate coordination of search and rescue operations, the first 24 h being of critical importance. It might be a sound planning strategy to have a shadow management team familiar with, for example, Vancouver's emergency preparedness plans, but be physically located outside the City.

The UNDP (United Nations Development Program) located in Ankara reported on September 2 that 46 countries provided assistance to Turkey following the earthquake (USAID 1999). Some of this assistance included a total of US$16 078 000 in cash contributions, 10 104 tents, 2276 search and rescue (SAR) team members, 224 SAR dogs, 23 ambulances, 66 318 blankets, 17 140 body bags, 709 medical personnel, and 290 electricity generators. A total of 35 Turkish and foreign vessels arrived at Turkish ports between August 17 and 30 to assist in the emergency response.

Typically tents were used for temporary shelter, an example being the camp constructed by the Canadian DART force (Fig. 17). Although intended as temporary, the DART personnel predicted that families could be occupying these encampments for as long as 3 years and planned the water distribution and sanitary waste system accordingly. A second style of semi-permanent shelter was observed (Fig. 18) adjacent to the DART tent camp. Twenty of these prefabricated units were under construction and, although in the short term these will provide improved shelter comfort compared to the tents, the concern is that they are too permanent and have the potential to develop into slum cities in the longer term. Given the urgency to provide interim shelter, minimal municipal planning engineering is carried out for the prefabricated housing. The number of units observed under construction was insignificant compared to the housing needs, and it is hoped that a coordinated assistance program proposed by the United Nations and World Bank will deliver a properly planned long term solution.

Summary and conclusions

Lifeline systems were severely tested in the Koecali earthquake. Highway and railway networks were efficiently reinstated in a matter of days and this opened access for the recovery operations. The availability of bottled water and of portable water treatment units stemmed a feared post-earthquake disease epidemic. The coordination of foreign aid teams with regional Governors' Offices facilitated the accelerated recovery of the infrastructure and the location and construction of emergency shelters.

There remains a challenge to rapidly assess the location and severity of damage immediately following an earthquake and to rapidly coordinate and deploy own and foreign aid teams during the critical search and rescue period. Satellite imaging technology offers a promising tool for immediate damage assessment.

There is no question that the enormous human impact in terms of loss of life from the Koecali earthquake will remain uppermost in the minds of researchers who had the opportunity to visit the epicentral region in the period following this devastating 1999 earthquake. Earthquake engineering professionals must maximise the lessons from the disaster both in terms of construction practice and of preparedness and take steps to mitigate the consequences of future events.

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