CHAPTER 10
Infrastructure Networks

GEER/EERI/ATC Cephalonia, Greece 2014
Report Version 1

10.1 Potable and Wastewater Networks

INTRODUCTION

This section is based on the contribution by the Organization EYDAP (ΕΥΔΑΠ in Greek), which is the Athens Water Supply and Sewerage Company (EYDAP SA). EYDAP responded rapidly and sent field investigation and repair teams to assist with the assessment and retrofit of the potable and wastewater networks of Cephalonia. A preliminary report on the action plan and retrofit work entitled "Emergency Support provided to the Municipality of Cephalonia for the repair of the damages which occurred after the January-February 2014 earthquakes" was prepared (in Greek) by the General Department of Networks & Facilities and the Departments of Potable Water Network Department and Waste Water Network / Quality Assurance Department and became available to our team for incorporation in the GEER/EERI/ATC report. This section was compiled by Mr. Dimitri Iliadelis of MRCE and Editors Zekkos and Nikolaou, based on excerpts from the preliminary EYDAP report and feedback from the reconnaissance teams that interacted with EYDAP personnel while in the island. The Editors are grateful to EYDAP for providing this report and information and especially thankful to Mr. George Sachinis of EYDAP who acted as our liaison with the organization.

EYDAP ORGANIZATION (ΕΥΔΑΠ)

EYDAP is the Athens Water Supply and Sewerage Company (EYDAP SA), founded in 1980 after a merger of the incumbent water supplier in Athens and Piraeus "Hellenic Water Company S.A." (EEY SA) with the "Greater Athens Sewerage Organization" (OAP S.A.). It is the largest organization of its kind in Greece. The Company serves approximately 4.3 million customers through an extensive network of 2 million water meters and 9,500 km of water pipes. The sewage sector serves 3.5 million residents with sewers spreading at almost 6,000 km. The company's objectives are to:

- Provide water supply and sewage services.
- Design, construct, install, operate, manage, maintain, expand and upgrade water supply and sewerage systems.
- Pump, desalinate, process, transfer, store and distribute all kinds of water as a means of serving EYDAP's object.
- Implement projects and processes for collecting, transferring, storing, processing, and manage and dispose the wastewater treatment products.

ACTION PLAN

EYDAP responded rapidly and sent field investigation and repair teams to assist with the assessment and retrofit of the potable and wastewater networks of the island. The EYDAP teams were supervised by the General Manager of Networks, Mr. Stefanos Georgiadis, the Deputy General Manager of Networks, Mr. Konstantinos Vougouklakis, and the CEO Mr. Antonis Vartholomaios.

Two teams were put together for the rapid immediate assessment and repair purposes in the central EYDAP facilities in the capital of Athens and immediately departed in order to arrive at the island as soon as possible (Fig. 10.1.1). These two teams were (i) potable water team, consisting of four mobile immediate response units and one mobile coordination unit and (ii) wastewater team with two mobile independent immediate response units.

Figure 10.1.1. EYDAP vehicles arriving from the central facilities in Athens to Cephalonia via ferry boat, with the investigation and repair teams members who were joined by local colleagues.

The mission team members included experienced engineers and technicians, carrying technologically most up to date equipment and vehicles to allow them to work efficiently and independently immediately following an emergency event. The engineers of the team are specialized and trained in emergency response assessments, crisis management, and collaboration with local agencies and communities. Concurrently with the rapid assessment and as-needed repairs, the EYDAP teams performed monitoring and chemical analyses of samples and collected network data to produce detailed GIS mapping of the potable and

wastewater networks. The investigation and repair teams worked uninterruptedly on 24-hour shifts until the networks were assessed and fully operable and all residents had access to potable water. Details of the potable and wastewater network EYDAP missions are provided in the following sections and can be seen in the video www.youtube.com/watch?v=Dyt7sZsrNYs .

POTABLE WATER NETWORK

Event No. 1 Investigation

The 1st earthquake event of January 26th 2014 did not produce alerting reports of major damage in the water supply network. However, EYDAP engineers and technicians trained in post-emergencies immediately travelled to the island to identify and restore any problems that could had occurred. The focus areas were the towns of Argostoli and Lixouri, where small scale restorations and minor repairs took place, since no major problems were identified. At the end of this investigation full functionality of the network was restored.

Event No. 2 Investigation

The 2nd earthquake event, on February 3rd 2014, caused significant problems in the water supply network. Immediately following this earthquake, an additional EYDAP investigation was engaged to support the restoration of the network. Large scale repairs and replacements took place until full functionality was achieved. The focus of the investigation was the town of Lixouri, were the majority of the damage was concentrated, especially in the aged portions of the networks. The actions taken in restoring the Lixouri networks after the 2nd event are presented below. EYDAP's personnel laconically summarized to the GEER/EERI/ATC investigators their mission goal in one sentence: *"We will not leave the island until each home is supplied with clean water."*

Preparation. The preparation was well planned and thought out by the following actions:

i. Formation of investigation and repair team
ii. Selection of vehicles and equipment support
iii. Collection of support information, including maps (Fig. 10.1.2), digital elevation models of the ground surface from satellite data (Fig. 10.1.3), and longitudinal sections of the water reservoir.

Figure 10.1.2. Digital Elevation Model (EYDAP, 2014).

Figure 10.1.3. Topographic map showing Lixouri water networks (EYDAP, 2014).

Deployment. Both investigation and repair teams departed immediately after the 2nd event at 1 am on Feb. 6th, to board the first available ferry boat to Cephalonia.

Rapid Assessment. The investigation and repair teams, in coordination with the local agencies performed a rapid assessment. Just 3 hours upon arrival to the island, the EYDAP teams were planning for the investigation and restoration activities. Fig. 10.1.4 shows a GIS map of the water network. The mapping involved a total of 36,191 m of pipes.

As shown in Table 10.1.1, the material of these pipes consist of PVC by 42.3%, Asbestos Cement by 30.5%, Polyethylene by 25.8%, and steel by 1.4%. A map of the network is shown in Fig. 10.1.4. The assessment of the first day is shown on the map of Fig. 10.1.5, color coordinated as follows: Green – normal operation; Yellow – significant fluctuations in pressures; Orange – very low pressure; and Red – zero pressure.

Table 10.1.1. Potable water pipe network material and length in the town of Lixouri.

Material	Length (m)	% of Network
Plastic Pipe Network (PVC)	15,295	42.3
Asbestos Cement Pipe Network (A/C)	11,041	30.5
Polyethylene Pipe Network (PE)	9,355	25.8
Steel Pipe Network (ST)	500	1.4

Figure 10.1.4. GIS mapping of a total of 36,191 m of potable water network pipes (EYDAP, 2014).

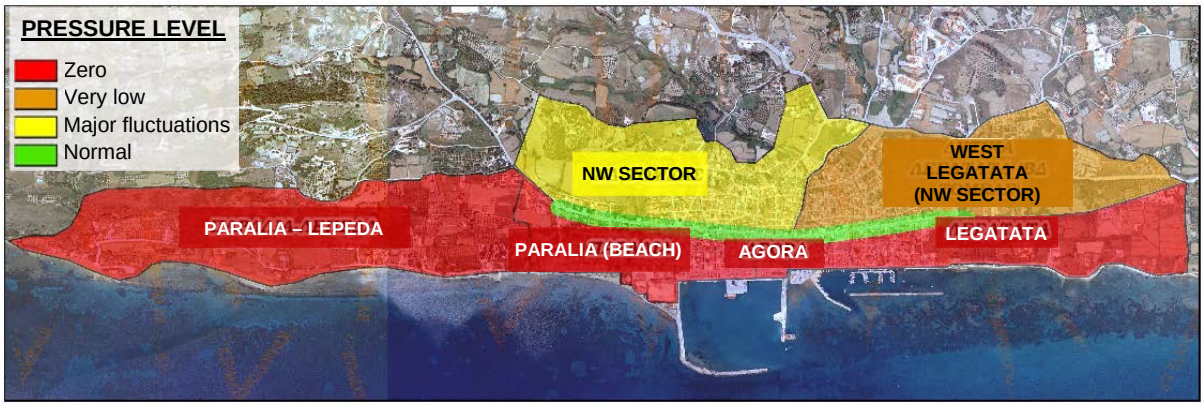


Figure 10.1.5. Rapid network assessment at the end of the first day (EYDAP, 2014)

Mapping activities: Electronic mapping of the water networks was not readily available by the local agencies. EYDAP formed a special task group responsible for digital mapping as this was considered necessary to assess the condition and performance of the networks.

Repair activities

Day 1: A second subgroup was responsible for detecting and repairing the visible damages and leaks. Photos of the repair activities during Day 1, a 24-hr shift, are shown in Fig. 10.1.6. Due to large number of leaks, most of the system could not maintain its pressure, so nineteen additional valves were installed for the control of the water supply in the various areas (Fig. 10.1.7). As shown in Fig. 10.1.8, at the end of the first day normal water supply was secured inland.

Day 2: The EYDAP teams gradually connected areas to the network and performed leakage tests. Once the system achieved positive pressures, "invisible" leaks were detected using acoustic methods as well as hydraulic numerical simulations that were employed to identify unexpected drops of the piezometric line and help in the detection of leaks (Fig. 10.1.9).

Days 3 to 12: During Days 3 to 12, the EYDAP teams inspected the water reservoir (tanks, pipes), repaired damages and performed continuous adjustments in order to ensure stable service. A bypass of the network pipes and alternative supply took place in areas where the repair would have been too difficult or where the upgrade in supply was significant. For the protection of the asbestos cement pipe network, a pipe rupture valve was installed since the repair of the leaks would result in increase of pressures in the already distressed network, which would likely cause new leaks. At the same time, in situ chemical analyses were performed (regular and residual chlorine) to ensure the water quality and also to check for leaks (which would decrease the quantity of the residual chlorine). The network pressures upon completion of these activities were normal, as shown in Fig. 10.1.11. Since Saturday February 8th 2014, 100% of the network in Lixouri and the surrounding areas was fully restored.

Figure 10.1.6. Examples of the numerous repair of leaks repaired (EYDAP, 2014).

Figure 10.1.7. Nineteen new valves were installed by EYDAP shown with red dots.

Figure 10.1.8. Progress made at the end of the first day (EYDAP, 2014).

During the field operations, the investigation and repair teams gathered information to generate a more detailed estimate of the hydraulic and mechanical network operations, in order to submit proposals for the improvement and support of the network. EYDAP's efforts have then focused in the management of the pressures and the application of modern technologies and special methodologies in network restoration. The organization considered that the main goal of maintaining a steady pressure in the network that is necessary to ensure the quality of the potable water was accomplished.

Figure 10.1.9. EYDAP Personnel repairing leaks during Day 2 (EYDAP, 2014).

Figure 10.1.10. EYDAP Personnel repairing leaks Days 3 to 12.

Figure 10.1.11. Potable water network fully functioning at the end of repair activities.

Challenges Associated with Repair Activities

The challenges faced by the EYDAP teams can be summarized into three categories: weather conditions, groundwater and social factors:

i. *Weather Conditions:* Rainfall not only made the efforts more difficult, but also affected the groundwater table elevation.

ii. *Groundwater:* The groundwater elevation, the presence of wells, and the storm water posed difficulties in assessing if potable water was spilling into the wastewater network. To overcome this difficulty numerous additional chemical analyses had to be performed to define the source of water entering the wastewater network. Several checks in locations where no leaks were present were carried out, causing delays in the repairs. Finally, it was established there was no potable water spill in the wastewater network.

iii. *Social Factors:* Most of the residents of Lixouri had evacuated their homes and as a result the network could not be tested and adjusted for usual operating conditions.

WASTEWATER NETWORK

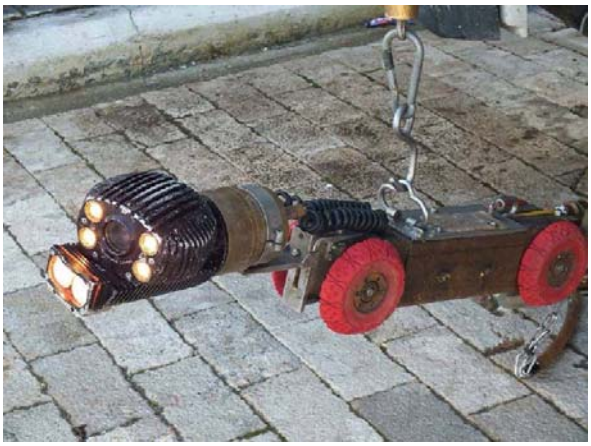
After the 2nd event of February 3rd, 2014, the network fatigue and high volume of water in the wastewater network resulted in serious operational problems, leaks and risks to the public health. Dedicated groups of experienced engineers and technicians were immediately deployed to the island to address these problems. Large scale inspections took place to evaluate the condition of the network. Most of the activities were concentrated in Argostoli and Lixouri. The mission of the wastewater teams was: "*We will not leave until have a complete picture of the damages and a recovery plan is set.*"

The investigation and repair teams arrived in Cephalonia on February 7th and remained there for six days as shown in Fig. 10.1.12. The investigation and repair team was equipped with the most recent technological equipment and vehicles in order to achieve its goal, as shown in Fig. 10.13.

Figure 10.1.12. EYDAP wastewater network mission field personnel arrived on 2/7/14 and worked at the island for six days. Photos by: (a) EYDAP; and (b) GEER/EERI/ATC reconnaissance team.

Camera for Imaging of sewer networks

Mobile Super 2000 water recycling sewer cleaning machine



Mobile unit and robotic camera for imaging assessment of the sewer networks.

Center of Operations

Figure 10.1.13. EYDAP equipment and field personnel for wastewater network.

Assessment of Existing Conditions - Actions

The investigation and repair wastewater network teams and the General Manager of Preventative Maintenance Office, Mr. Elias Karambelas, in coordination with the local agencies immediately assessed the existing conditions and started in-situ as well as video inspections. More than 4 km of wastewater pipes were inspected in the towns of Lixouri and Argostoli and 700 m of wastewater pipes were video inspected. Fig. 10.1.14 shows photos provided by EYDAP from these the field operations. Fig. 10.1.15 present examples of damage identified using the video inspection information.

To ensure the uninterrupted operation of its network, EYDAP installed advanced telemetry systems in crucial locations for continuous monitoring of the most important components of the system. The main components which are continuously monitored since the earthquake are: elevations, water flows, and pressures.

Figure 10.14. EYDAP equipment and field wastewater network personnel.

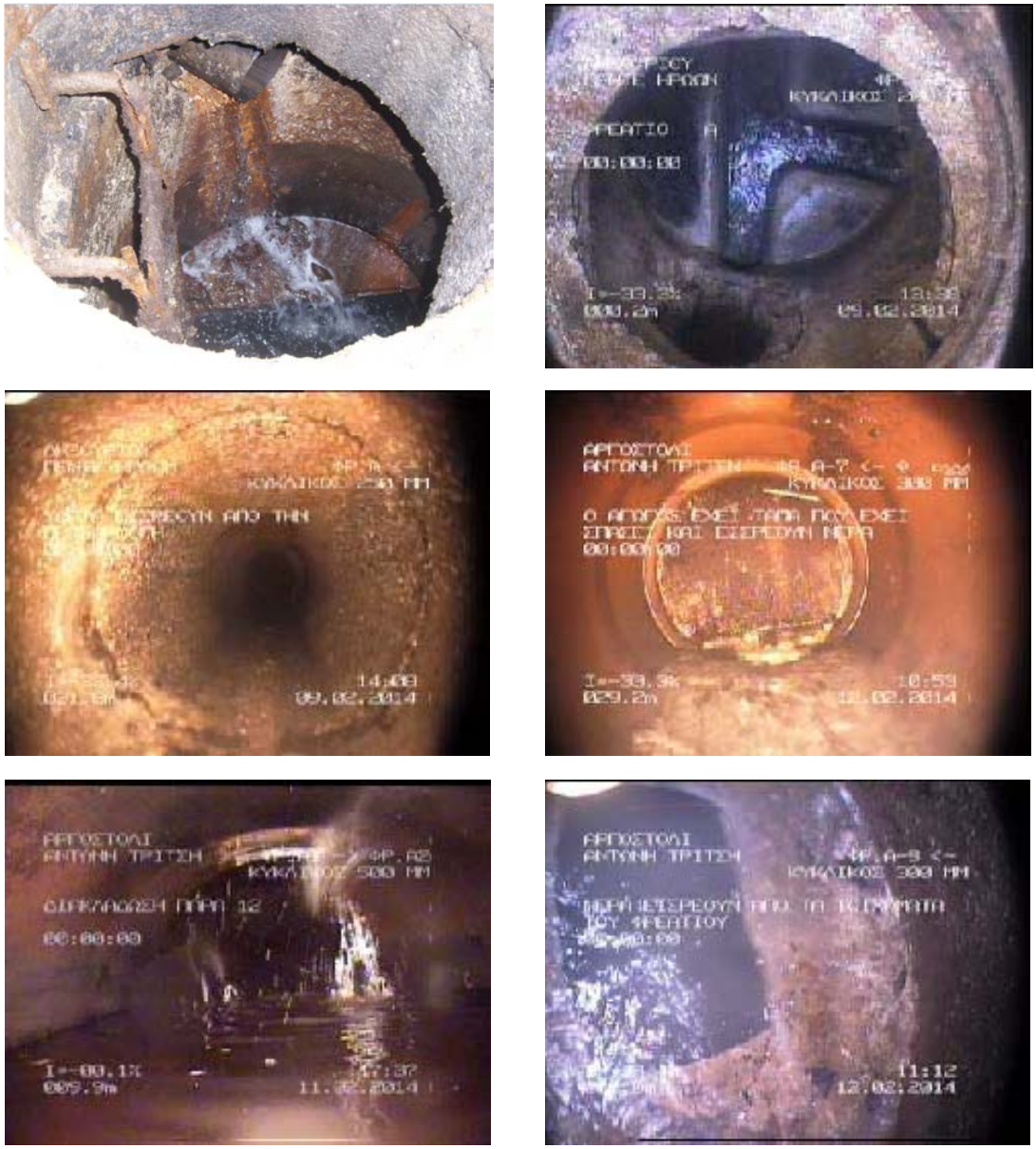


Figure 10.1.15. Video inspection shots (EYDAP, 2014).

CONCLUSIONS

The potable and wastewater networks suffered notable damage mainly due to the 2nd event. EYDAP responded rapidly and sent field investigation and repair teams to assist with the assessment and retrofit of the potable and wastewater networks of Cephalonia. At the end of the field missions, the EYDAP organization achieved their goals of leaving the island ensuring that: (i) each home was supplied with clean water and (ii) all damage is assessed, a recovery plan is set and key parameters are continuously monitored.

10.2 Transportation Road Network

INTRODUCTION

The first larger roads were built by the English in the 19th century. In the 20th century asphalted roads were built, and since 1995 almost all streets connecting villages and beaches are covered with asphalt. By 2000, the road network was enhanced with the Lixouri bypass and a 4-lane street south of Argostoli. Currently the most important roads are (Fig. 10.2.1):

- Greek National Road 50, commonly Argostoli-Sami Road
- Argostoli-Poros Road
- Argostoli-Fiskardo Road (with link to Lixouri)
- Road linking Poros and Sami

Figure 10.2.1. Main Cephalonia road network (modified from inagiaefimia.com).

This section presents observations related to road transportation network performance and traffic disruptions during the two seismic events and their aftershocks. In general, the main road network performed well, with problems mainly in the Paliki peninsula area (Fig.10.2.1). Following the 2nd event, the authorities preemptively shutdown the horse-shoe shaped Argostoli-Lixouri main asphalt road. The traffic between the two towns was available only by ferry boat that was offered free of charge to the commuters.

OBSERVATIONS

The performance of the road transportation network was mostly affected by the response of road embankments and retaining walls and less of the bridges. Overall, the (small) bridges of the island responded well to the two main events and their aftershocks and none of the bridges collapsed or suffered severe enough damage to close down traffic. The only exception was observed in the Havdata bridge (38°12'10.30"N, 20°24'16.05"E), where traffic was partly interrupted due to excessive settlements in both access embankments, as shown in Fig. 10.2.2. For more details on bridge behavior, see Section 8.5.

Figure 10.2.2. Settlement of western embankment of Havdata bridge, recorded by reconnaissance team members S. Nikolaou and M. Moretti (38°12'10.30"N, 20°24'16.05"E).

The road embankment inventory of Cephalonia includes many, rather short, road embankments retained by masonry walls and, to a lesser extent, by reinforced concrete walls. The response of the embankments, as described in Section 8.6, was satisfactory, meaning that the roadway network had partial traffic interruption immediately following the two events. Some notable exceptions that affected traffic include severe damage of the access road to Myrtos beach due to major rockfalls (38°20'16.20"N, 20°31'56.34"E) and extensive cracking of the embankment (38°10'42.84"N, 20°24'2.96"E and 38°10'39.79"N, 20°23'50.90"E) that affected the whole width of the road connecting the Chavriata and Vouni villages (see Section 8.4). There are several locations in the Paliki peninsula area, where moderate damage occurred at road embankments mostly related to sliding within the embankment material as was observed in the asphalt road (38°14'17.17"N, 20°25'44.30"E) joining the Aghios Dimitrios and

Livadi villages (see Section 8.6.1). Figure 10.2.3 presents the large downslope displacement of a circular sliding mass in clayey soil on the order of 40 cm in the vertical direction that affected a country road embankment north of Soullari village. Note that a detailed map with a list of towns with their coordinates can be found in Section 2.2.

Figure 10.2.3. North of Soularoi road embankment sliding, as viewed from the pavement (38°11'21.51"N, 20°24'45.80"E).

Moderate roadway embankment damage was also related to total collapse of the masonry walls and was recorded along the main asphalt road connecting Argostoli to Lixouri, and to the NW of the village of Kardakata. Figure 10.2.4 shows the collapsed masonry wall which had supported the road embankment, as seen from the downhill side after the 2nd event. In addition, there were numerous road embankments along the eastern portion of the main asphalt road connecting Argostoli and Lixouri which suffered minor longitudinal cracks and small settlements of the asphalt pavement that caused only some local traffic diversions.

Figure 10.2.4. Masonry wall collapse in NS direction of Kardakata road embankments after 2nd event (38°17'34.61"N, 20°27'8.16"E).

Traffic problems were caused not only by damage in bridges and road embankments, but also due to rockfalls and slope instabilities which, in most cases, partially covered the pavement interrupting traffic as shown on Fig. 10.2.5 from the Aghia Thekla village road (38.25°N, 20.3833°E). Several rockfalls were observed north of Argostoli bay (e.g., 38°17'13.43"N, 20°26'52.89"E) and on the road from Argostoli to Sami (38°12'20.47"N, 20°36'25.76"E).

Figure 10.2.5. Rockfalls in Aghia Thekla village road (38.25°N, 20.3833°E from inkefalonia.gr).

Figure 10.2.6. Rockfalls at main asphalt road connecting Lixouri to Argostoli. Web photo from madata.gr after the 1st event.

The most severe problems caused by rockfalls were observed at the main asphalt road connecting Lixouri to Argostoli (Fig. 10.2.6). Especially the eastern portion which was closed to traffic for at least 15 days (since the 1st event, 1/26/14, and at least one week after the 2nd event, i.e. at least until 2/10/14) due to concerns of loose rocks falling on the pavement during aftershock activity. The road was uninterruptedly cleaned from debris during the shutdown period, and especially after intense aftershocks when additional minor rockfalls were recorded.

Along village roads, damage on buildings and retaining walls caused traffic interruptions, since these roads are very narrow. Examples of building damage-related closed roads were found in Havdata (38°12'14.80"N, 20°23'10.03"E) and Kourouklata villages. The retaining wall of The Virgin Mary church (Fig. 10.2.7) at Chavriata (38°10'57.32"N, 20°23'14.48"E) caused road closure (detailed observations on retaining walls are provided in Section 8.3). At these locations local authorities used road safety cones and “do not cross” lines to locally divert traffic. Debris collection from roads was in progress when our reconnaissance teams visited the island and no retrofit work was underway due to concerns of aftershock activity.

Figure 10.2.7. Collapse of masonry wall at courtyard of The Virgin Mary church at Chavriata, which caused local traffic disruption (38°10'57.32"N, 20°23'14.48"E).

Figure 10.2.8. Traffic disruption due to nonstructural elements damage in Krasopatera Street, Lixouri (38°11'36.81"N, 20°26'11.42"E).

Nonstructural elements damage, including massive chimneys of large quantities roof tiles, interrupted traffic in urban areas. When the GEER reconnaissance terms visited the island only some of the debris had been removed from the roads to allow for pedestrian crossing, and in most cases it was still in place (e.g., in the narrow back-streets of Lixouri). An example is shown on Fig. 10.2.8 at Krasopatera Street in Lixouri (38°11'36.81"N, 20°26'11.42"E).

In conclusion, the road transportation network of Cephalonia was not severely affected by the earthquakes. The effects were smaller after the 1st event and were aggravated after the 2nd one. Traffic was interrupted in the Paliki peninsula area and some problems were recorded on the eastern portion of the main asphalt road connecting Argostoli to Lixouri. Noteworthy traffic problems in the rest of the island were very scarce. Traffic disruptions were mostly related to damage of the transportation infrastructure (road embankments, with or without masonry retaining walls), and less to falling debris (rockfalls, or collapse of neighboring buildings and retaining walls). In general, the local authorities were able to divert the traffic where required. The only occasion where severe traffic problems occurred was during the preemptive shutdown of the Argostoli-Lixouri main asphalt road after the 2nd event, which was substituted by the free-of-charge ferry boat service between the two ports.