# HIGH PRECISION LEVELLING NETWORK OF COMO AREA FOR SUBSIDENCE ANALYSIS

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## ABSTRACT

The levelling network of Como was completed and improved in 1997 for better analysis of land subsidence by the Surveying Department of the Politecnico of Milan. This paper firstly describes levelling measurements made in the past, and then deals with design and measurement of 1997 network. New measurements have compared to the past results, starting from 1975 campaign. A few students of the Politecnico's Seat of Como partecipated to this project and so they did an important experience for their training.

## 1. LAND SUBSIDENCE IN COMO AREA

Many Italian regions are affected by land subsidence phenomena, resulting in instability problems to buildings, streets, pipes and so on. Some important historical and artistic settlements suffer from this problem too. Variation of ground height can result in modifying the structural behaviour of buildings and reaching the collapse state. The Cathedral of Milan, ancient churches and palaces in Ravenna, Pisa, Bologna and Venice are the most famous and well-known examples. Further information on these cases can be found in reference. In urban and industrialised areas, especially on lake and see shores, land subsidence implies considerable economic losses, because of flooding.

Land subsidence can be due to natural or to human causes. The first ones, having gravitational and geodynamic origin, produce deformations slowest and in widest area, instead the second ones, causing space and time localised deformations, can follow mining activities (e.g. gas, hydrocarbon and similar), water drawing, land draining, etc. (see Viggiani, 1978; Carbognin et al, 1978a).

Studing the subsidence problem is very important in order to discover its origin and to take measures for controlling its development (e.g. by slowing down water drawing, by consolidating constructions, etc.). Subsidence analysis involves several disciplines: geology, hydrology and soil mechanics for analysing the soil behaviour, and surveying sciences for measuring and monitoring height variations of the ground.

This paper describes the case of Como town, where land subsidence was observed firstly at the beginning of 70's and then it have been carrying on until nowadays. Como, placed in Northern Italy on the edge of the homonymous lake, stands in an area almost complex for geological aspects. Its centre, closed inside Medieval Walls, lies over a valley bottom made up of sedimentary drift, while its suburbs go up the hilly belt which surround it. The presence of a large built-up area on the lakeshore makes land subsidence to have very dangerous effects, so that it is very important to performe a regular and continuos monitoring of soil deformations in this area, especially in order to take action to avoid flooding.

In particular in the following we focus on topographic measurements carried out for evaluating land subsidence evolution in the time in Como area. Several levelling measurements have been accomplished since the end of the last century. Until 1975 measurements have been taken without any specific goal of looking into land subsidence. But in 1974, when the authorities of Como decided to indagate on this problem more carefully, previous measures have been used for analysing how land subsidence has been developping until nowadays.

In 1997 the levelling network of Como was completed and improved for a better analysis of this phenomenon. The Surveying Department of the Politecnico of Milan (DIIAR) was entrusted with doing it.

Firstly this paper describes levelling measurements made in the past, and then deals with design and measurement of 1997 network.

A few students of the Politecnico's Seat of Como partecipated to this project and so they did an important experience for their training.

## 2. LEVELLING MEASUREMENTS IN COMO AREA

Already in 1877-78 Prof. Oberolhtzer carried out a levelling network in Como area (the Camerlata-Como–Chiasso line) for an international project concerning the area between Italy and Switzerland (results were published in 1910). Unfortunately, the most part of the monuments were lost or damaged and no comparison with the fol-

lowing measurements is possible. The same problem concerns levelling measurements carried out by IGMI (Istituto Geografico Militare Italiano, the official Italian authority for mapping and surveying) from 1879 to 1955. Deformation study cannot be performed due to few points shared among diverse network, to different zero values (Genoa marigraph and Helvetic Network zero) and to many unsteady points. However, these first measurements were made to link the town of Como to a regional levelling network for geodetic purposes; for this reason, monuments standing in this area are few and moreover they are not well distributed.
In 1928 Como Town Council charged IGMI to carry out a local levelling network in order to measure points throughout the town area. Prof. E. Quaglia by IGMI measured 5 benchmarks of 1877 network and 260 new ones placed in the town as well as along levelling lines to Chiasso, Torno, Erba and Varese. When this network was designed and accomplished the land subsidence problem was not observed yet, but such a levelling network would have be suitable to be used for controlling height variations of the ground in the time. Despite of this, nowadays many of these points are lost or precarious.
Levelling measurements carried out until 1928 are not available for analysing the evolution of the land subsidence in this area, because comparisons cannot be correctly done between measures taken in different ways.
No important measurement were accomplished until 1955, when IGMI carried out a new high precision height network. The Como area was crossed by three lines (*59*, *58* and *ES*) all starting from point number *14* placed in the Como downtown. This network contained 17 benchmarks all well materialised and defined in gully holes (5 were previous). The 15 monuments of this network (2 are now lost) have been incorporated in the following networks and used for the following deformation analyses.
At the beginning of 70's some cases of building instability, especially in the part nearby the lake, and frequent flooding revealed the presence of land subsidence in the town area. These findings incited Como Town Council to designate in 1974 a special Commission ("Commissione di studio per i Fenomeni di Subsidenza nell'Area Urbana della Città di Como") for studing the subsidence problem and for promoting some solutions. The analysis carried out covered diverse aspects of the problem: urbanistique evolution, state of the buildings, soil geology and geotecnique, underground water, vertical ground displacements in the time.
In 1975 IGMI was entrusted to carry out a new levelling network for subsidence analysis. The new network contained 30 monuments of 1928 network, the 17 ones of 1955 high precision network and 9 new ones, was suitable for subsidence monitoring. The network was measured following high precision levelling rules and using high quality instruments, such a Zeiss Level and a couple of invar roads; measures were empirically adjusted.
Measurements of this network were repeated in the same way after (1979, 1981, 1983, 1985, 1990); in the time new points were integrated in those zones where the control should be intensified. In 1983 some important monuments were added on the outer breakwater.
More details about the levelling networks which have been carried out in the past can be found in Arca and Cardini (1984).

## 3. EVOLUTION OF LAND SUBSIDENCE

In 1980 the land subsidence Commission gave first results about evolution of the problem in the time (Comune di Como, 1980). From 1955 monuments heights are correctly comparable each other in order to make subsidence remarks. The first comparison (1955-1975) reported a lowering of the Duomo-S.Bartolomeo area about 30 cm. Further lowering of the downtown ground have been also showed by comparisons with the 1979, 1981, 1983 and 1990 measurements.
The Commission concluded with pointing out two notes:

- the subsidence beginning can be evaluated in the period 1945-50, with an initial quick development and then a substantial slackening (mean lowering speed was in the period 1975-79 about 10 mm in a year and in 1983-90 period about 3 mm in a year);
- the town centre is the area that is more interested by the problem as well as areas near lake's edges; land subsidence considerably decreases in the hilly belt around Como.

The height speed of deformation in period 1950-80 can be explained with great water extractions from deep ground water level for industrial and civil uses.

## 4. 1997 LEVELLING NETWORK

In 1997 Como Town Council entrusted Prof. A. Giussani (Surveying Department - Politecnico of Milan) with executing new levelling measurements.
First of all it was necessary checking the existing control network and completing it with new benchmarks and then carrying out new measurements. All the 73 monuments of the IGMI 1995 network were been controlled (the lost 9 of them were replaced with new ones) and classified (type and position). Then the network shape was optimised and checked with a priori simulation. Other 31 new monuments were made in order to reduce the branch length between couples of monuments; those new monuments take place of some temporary points of the old network shape. In this way the network geometry does not change and if some network parts have to be measured again for tolerance problems, they are faster measured again. In such way the control points number increases and so the subsidence monitoring is more precise and punctual. Figure 6 shows 1997 Como levelling network, made up of 104 monuments throughout the town. The network is composed by a central kernel with four indipendent rings, covering all the downtown, that is the area mostly interested by land subsidence. The external part of the network consists of 5 main single lines, linking downtown to Como's suburbs. One of these arrives as far as the reference monument (59/64 in Camerlata, at ≅ 4 km from downtown), placed outside the area more intensively affected by land subsidence phaenomena. Single lines were measured twice, in order to check data acquired. The total lenght of all the lines sums up to 51 km.

## 5. MEASURING OF LEVELLING NETWORK

Levelling measures were taken with a *Zeiss* NI1 Level using invar roads. Two size of roads were used: 2 m for flat sections of levelling lines and 3 m for tracts with slope.

The group of surveyors of the Politecnico of Milan, with the supervision of Prof. A. Giussani took the measures in the period from 06/03/1997 to 22/04/1997.

High Precision Levelling methodologies were accurately followed in carrying out measure operations. Monuments were linked each other using transitory points so that very single levelling measures links points remote less then 50 m and each measure was repeated at least 4 times in order to have residuals less than 0.1 mm. During measurements every ring, made up of $n$ measures, was repeated till the closing error was less then the permitted tolerance $\zeta$, evaluated as:

$$\zeta = 0.2\sqrt{n}\ [\text{mm}]$$

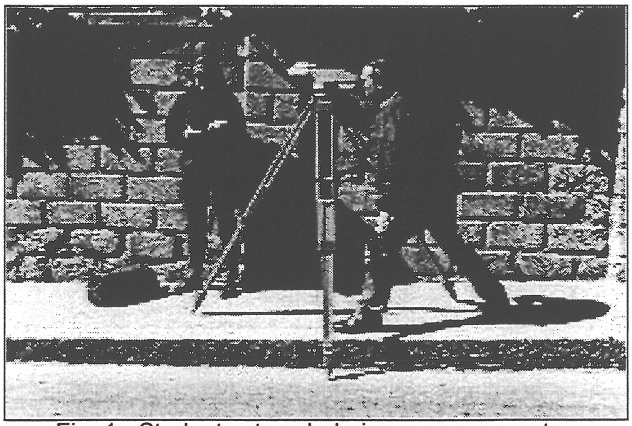

Fig. 1 - Students at work during measurements

## 6. STUDENTS STAGE DURING LEVELLING MEASUREMENTS

Ten students of the Surveying Course of the Politecnico of Milan (Seat of Como), partecipated to design and measurements of the levelling network.

Firstly they verified conditions of the IGMI monuments (status, position and type), then they selected which ones could be used again and projected the new network shape. After students helped the Surveying Group personel in levelling measurements, that lasted about one month. The continuous avaibility of students speeded up all the procedures. Several operations could be carried out contemporaneously, such as positionning of invar roads, measuring by the level, writing and checking data and finding out next monuments. Moreover it was a good occasion for putting into practice what students have learnt during courses. Figure 1 shows some students at work during measurements.

## 6. DATA ADJUSTMENT

Measured were adjusted by a least square approach using Level Program made by the Surveying Group of the Politecnico of Milan. The 850 measures of the network were adjusted all together having as constrained point the IGMI 59/64 monument.

The program gives as output the adjusted monument heights and their RMS. The RMS values are always less than 0.15 cm and they agree with standard high precision levelling uncertainty.

## 7. VARIATION ANALYSIS

Ground heights obtained by 1997 levelling measurements have been compared to the past results, starting from 1975 campaign. No comparisons with previous levelling measurements have been possible, because the monuments of the oldest networks have been lost and the reference point of 1928 network is different from that is actually used.

The total and partial height variations of the monuments were been calculated in order to analyse the land subsidence phaenomena. The total variations are always referred to the zero data (1975) and so they show the deformation history and its total amount. Partial variations are instead always referred to the previous data and so they permit to find and analyse the different soil behaviour in the years 1975÷1979, 1979÷1981, 1981÷1983, 1983÷1990 and 1990÷1997. Different behaviours can be related to changes in the environmental conditions and, obviously, to probable causes of subsidence such as water drawings from groundwater level.

A point set, made up of 21 IGMI monuments, is selected with the aim of covering the whole area of Como town and shows the distribution of height variations. The subsidence phenomena are then visualised with maps showing isolines and translation vectors. Figure 7 shows an example of map with isoline and Fig. 8 shows an example of map with translation vector. In order to visualise better the different behaviour of the various Como zones, Figures from 2 to 5 show variations of monument heights along two cross-sections. Monuments 38 and 162 were placed in 1979 and so in Fig. 2 their values were estimated by interpolation of nearest measures. Monuments 112 and 60 on lakeshore, and monuments 40 and 42 on Cavour Square (close to the lake), show higher deformations for the area near to the lake. The Como zones far from the lake instead have deformations lower and more homogeneously distributed.

The analysis of 1997 levelling campaign, compared to those from 1975 and following, shows that the part of the town on the lakeshore is slowly lowering. In this area the sinks from 1990 to 1997 get until 20 mm, with peaks which overtake 30 mm for the monuments placed on the outer breakwater. These values appear very similar to those of the previous period from 1983 to 1990, confirming that the land subsidence is not breaking. However the lowering also seems to be not quick as in the period from 1975 - 1981.

## 8. FINAL REMARKS

The measurement campaign leaded by the Politecnico of Milan can be considered satisfactory for the obtained results. The large amount of monuments have been suitable to measure height variation fo the ground on the whole town area, and accuracies reached in point measurement are like the expected ones .

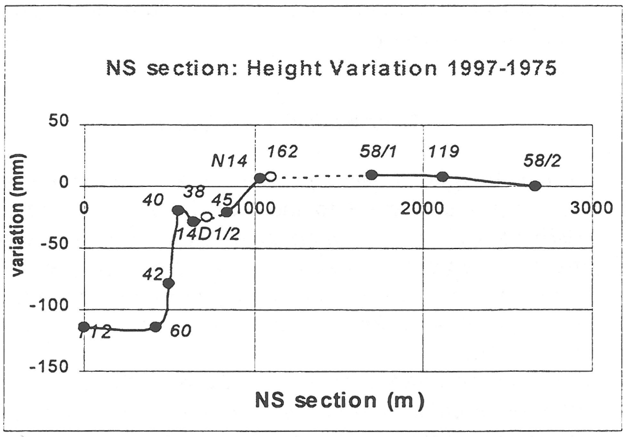


Fig. 2

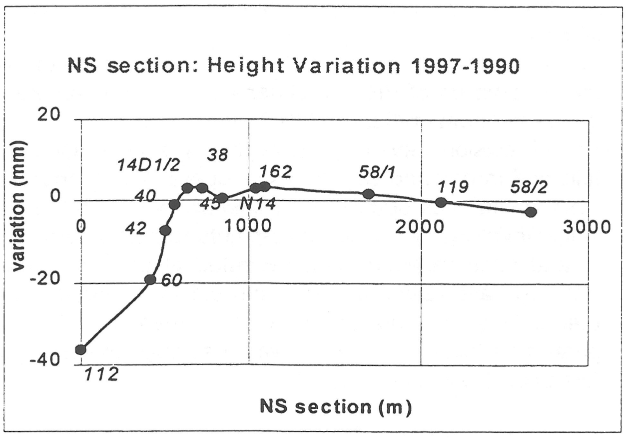


Fig. 3

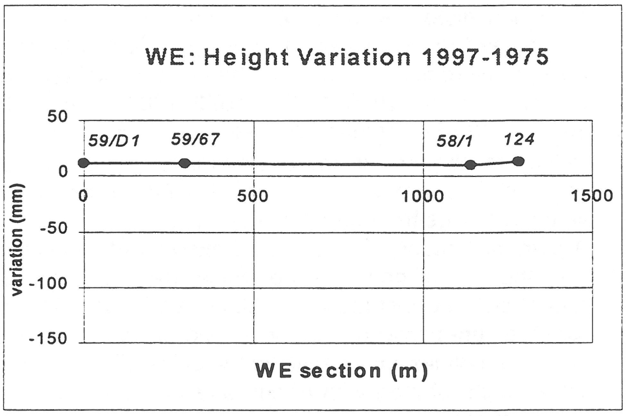


Fig. 4

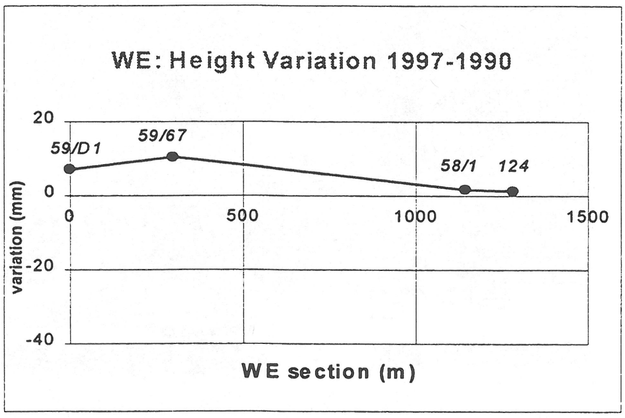


Fig. 5

This methodology still suffers from long time required for carrying out levelling measurements, even though the job has been accurately planned in order to reduce operations to do. High ability of the surveyors of the Surveying Departement as well as the continuous presence of students permitted to proceed very fast in measuring.

In the future measurements will be periodically repeated to carry on land subsidence monitoring. Network will be improved by a few new points in zones more interested by height variations, such as downtown and lakeshores. Moreover, some tests on the use of GPS joint to levelling measures will be executed.

## Acknoledgements

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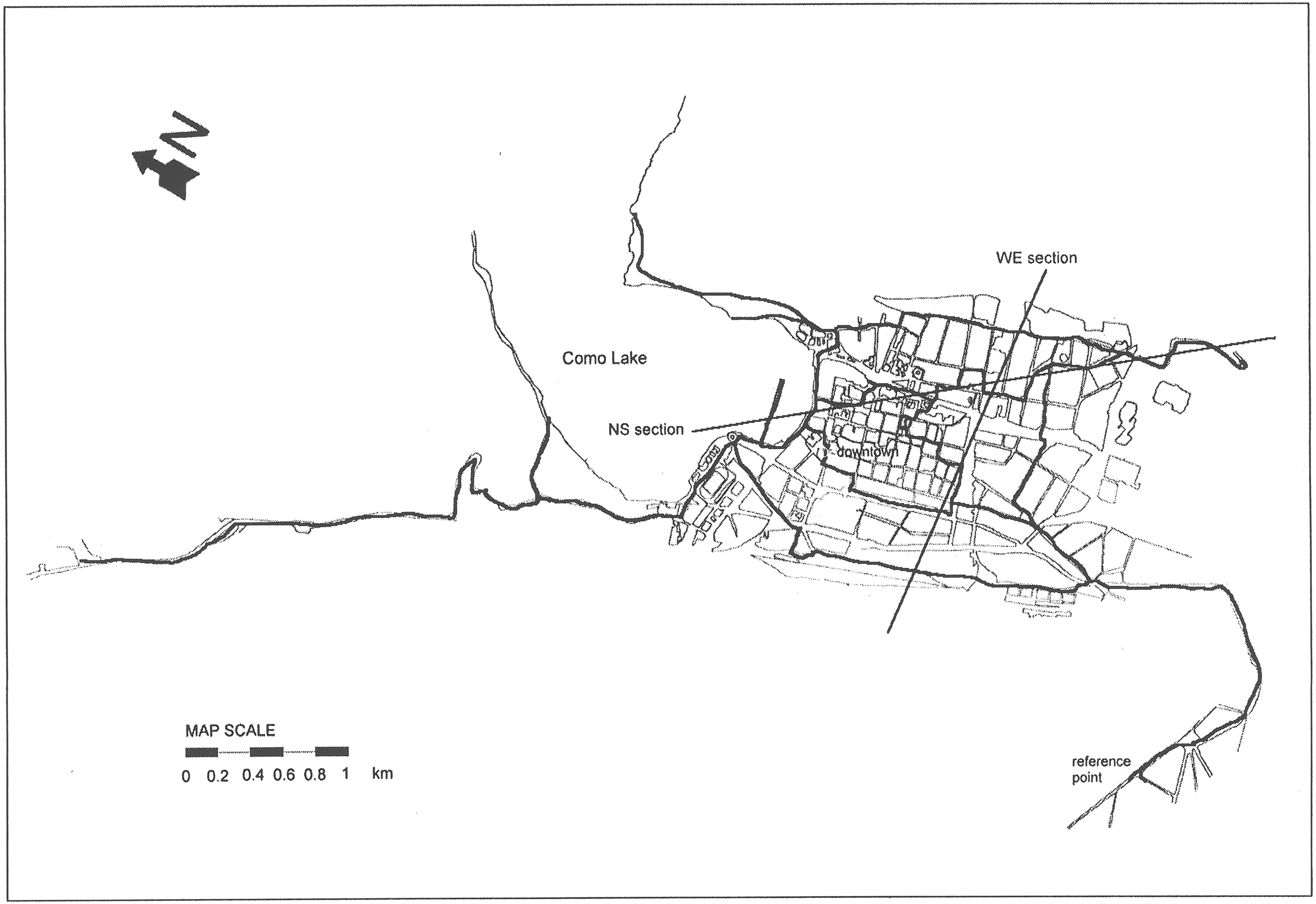


Fig. 6 – Map of 1997 Como Levelling Network

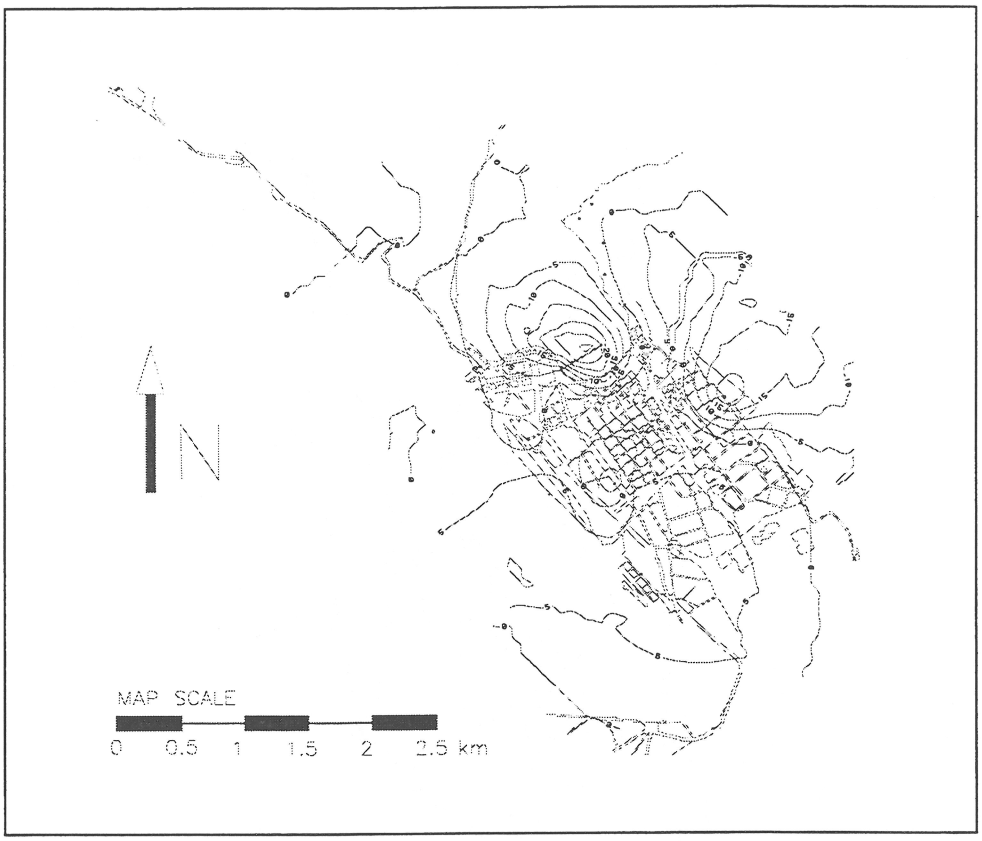


Fig. 7 – Isolane map of partial variations between 1990 and 1997

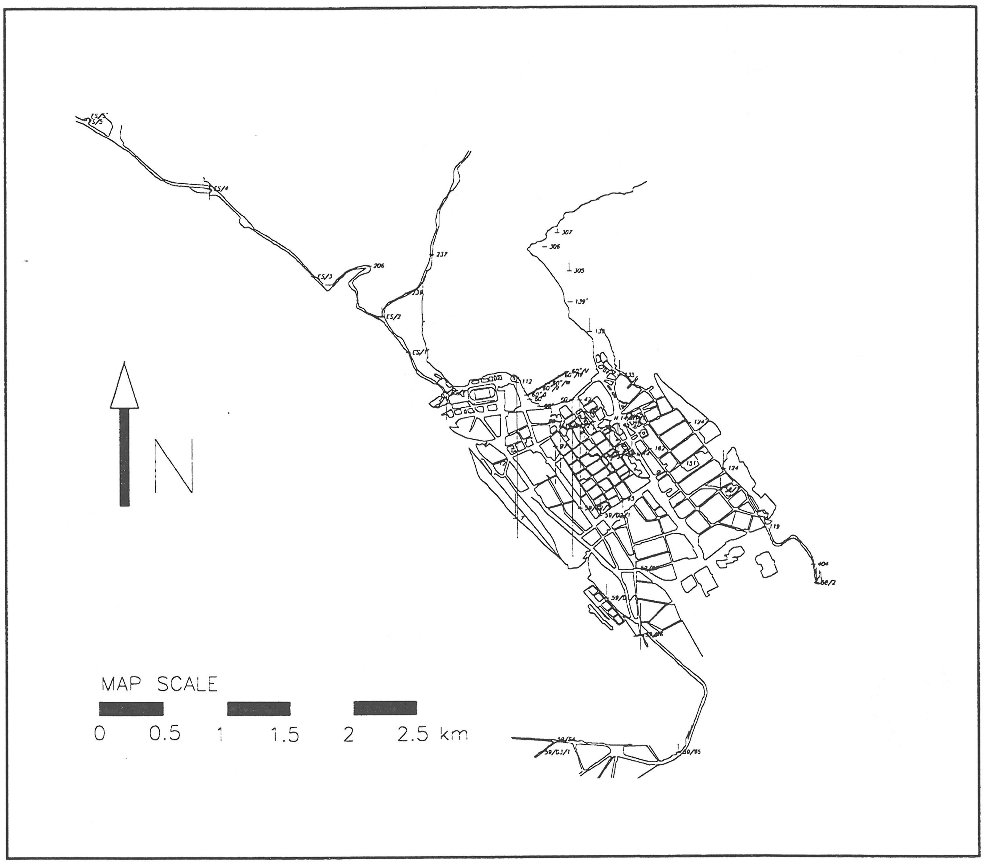


Fig. 8 – Translation vector map of total variations of levelling monuments between 1975 and