# Chapter 8

# Site effects in the cultural heritage areas of the City of Catania

S. Grasso & M. Maugeri
*Dipartimento di Ingegneria Civile e Ambientale, Università di Catania*

## Abstract

The city of Catania has been recognized as a typical Mediterranean city at high seismic risk. One of the peculiarities of this Mediterranean city is that there are many monuments and historical buildings. Recently some Churches were damaged by the moderate earthquake of December 13, 1990 with a magnitude M = 5.8. Because of that, to preserve the Churches from the damage which could be caused by a much stronger earthquake scenario (M = 7.0), an analysis of local site effects in the areas where the Churches are located was performed. The analysis was made on the basis of geotechnical site characterization by specific investigations or by the available data from the database implemented in the Land Information System (LIS) of the city of Catania. The location of the 108 Churches was also implemented in the LIS, as well as the location of the 910 existing boreholes. So, by a simple query, the Geographical Information System (GIS) gives the nearest borehole to the Church area considered. On the basis of the given geotechnical properties of the foundation soil up to a depth of 30 m, the soil response analysis was performed by a non-linear 1-D model. The results show a great variability of response from site to site where the Churches are located. For each Church the time history of displacement, velocity and acceleration were evaluated as well as response spectra.

## 1 Introduction

Since the beginning of the Project: Detailed Scenarios and Actions for Seismic Prevention of Damage in the Urban Area of Catania (Maugeri [1]), Catania was recognized as a typical Mediterranean city at high seismic risk. One of the

WIT Transactions on State of the Art in Science and Engineering, Vol 8, © 2005 WIT Press
www.witpress.com, ISSN 1755-8336 (on-line)
doi:10.2495/1-84564-004-7/08

peculiarities of this Mediterranean city is that there are many monuments and historical buildings. The Churches of Catania make up a unique chapter in the architectural scenario of our country; mainly built or rebuilt after the earthquake of 1693, in Catanese Late-Baroque style, they show architectural and structural characteristics that can be found in other parts of Italy only with great difficulty. The development plan is often rather articulated, a typical feature of the eighteenth century both in the search for a formal originality (Churches with a central layout) and because the buildings had to fit in with a town that was already heavily urbanized. Almost always the churches are close to other buildings and in many cases they are completely incorporated in the other buildings, being recognizable only by their facades that look out onto the public spaces; this is, for instance, the case of the Churches that are part of the monasteries and convents which are very numerous in the town (Cherubini *et al.* [2]). Recently the Sicilian Baroque of the Val di Noto has been included among the world cultural heritage by Unesco. The Baroque must be preserved from seismic damage due to any earthquake scenario (Priolo [3]) which could occur in Catania. In spite of the fact that the earthquake scenario could reach a magnitude M = 7.0, the moderate Sicilian earthquake of December 13, 1990 with a magnitude M = 5.8 (Laurenzano and Priolo [4]) caused some damage to certain Churches. Because of that, to preserve the Churches from the damage which could be caused by a much stronger earthquake scenario, an analysis of local site effects in the areas where the churches are located, was performed. The analysis was made on the basis of geotechnical site characterization by specific investigations or by the available data from the database implemented in the Land Information System (LIS) of the city of Catania. The location of the 108 Churches was also implemented in the LIS, as well as the location of the 910 existing boreholes. So, by a simple query, the Geographical Information System (GIS), gives the nearest borehole to the Church area being considered. On the basis of the given geotechnical properties of the foundation soil up to a depth of 30 m, the soil response analysis was performed by a non-linear 1-D model.

## 2 Site characterization at the Church areas

The areas where the 108 Churches are located were inspected and localized in the map of Catania city. All the sites have been located and geo-settled in the GIS database (Fig. 1). In the GIS database are implemented the 910 existing boreholes (Grasso and Maugeri [5]), the geological map (Monaco *et al.* [6]), as well as the geotechnical map giving the shear waves velocity of the upper 30 m of soil (Grasso and Maugeri [7]).

For the Churches damaged by the December 13, 1990 earthquake, a detailed site investigation was made. In particular, at the Saint Nicola alla Rena Church site, boreholes, a Down-Hole test and geo-seismic survey were performed (Cavallaro *et al.* [8]). At the Purità Church site, boreholes, SPT and laboratory tests were performed (Cavallaro *et al.* [9]). Other specific site investigations, consisting of boreholes, SPT and laboratory tests were performed at S. Agata La

Vetere site. Fig. 2 shows a plan view of the Church with the borings location; Fig. 3 shows a photo of the main prospect of the Church.

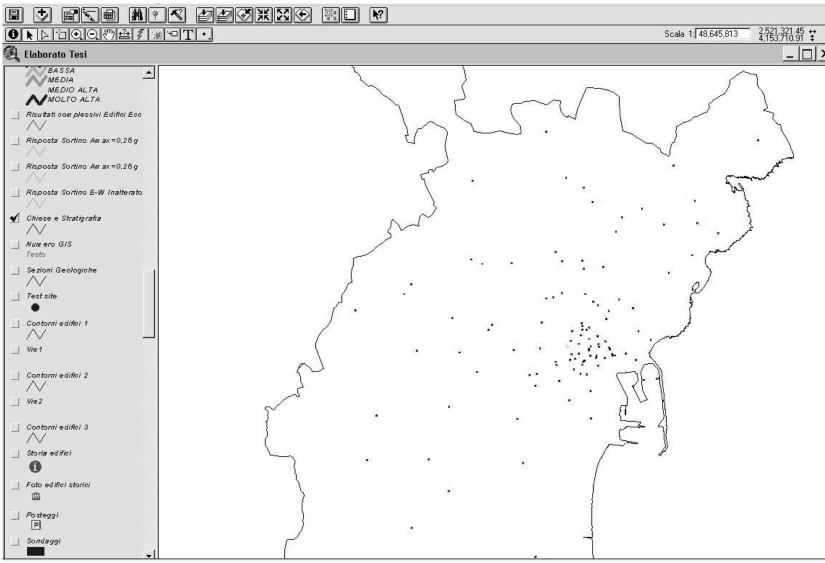



Figure 1: Localization of the 108 Churches in the GIS database of the city of Catania.

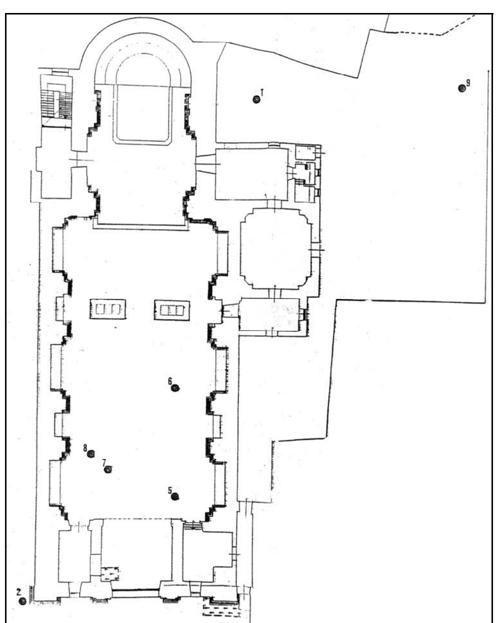



Figure 2: Plan view of the S. Agata La Vetere Church with borings locations.

Figure 3: Main prospect of the S. Agata La Vetere Church.

Similar specific investigations were made at Saint Sebastiano Church. The plan view of the church and the location of the borings are reported in Fig. 4. Among the other Churches considered, which could be damaged by the M = 7.0 earthquake scenario, Figs. 5, 6 and 7 report respectively the Cathedral, the Collegiata and the Stesicoro Churches. For the site characterizations of these Churches and of the remaining ones by checking the GIS database, the nearest boring was considered. If the nearest boring was farther than 100 m from the Church site, a set of borings were considered and by the interpolation of data the stratigraphy at the site was established. This stratigraphy was checked by a query to the geological map and the geotechnical map, to obtain the final stratigraphy at the site.

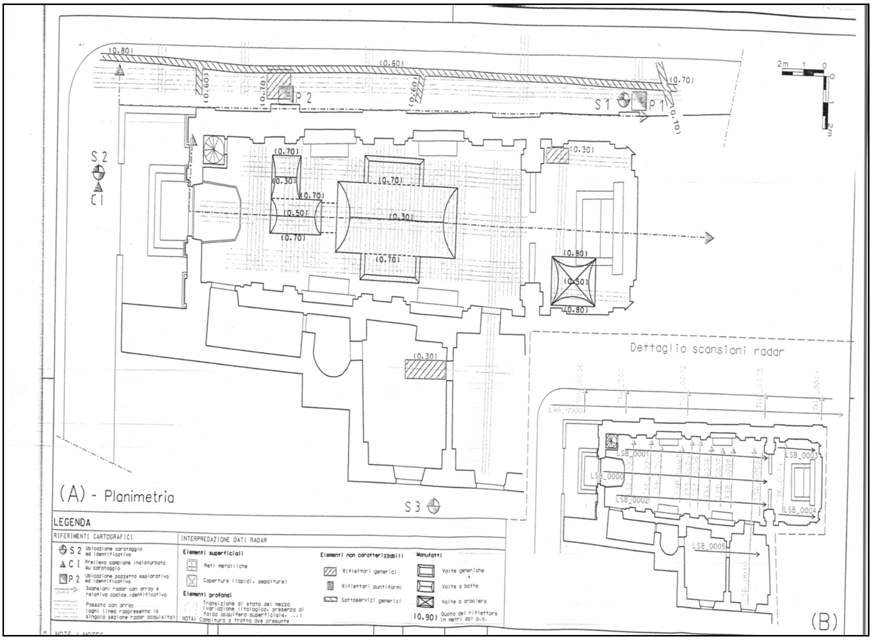



Figure 4: Plan view of the Saint Sebastiano Church with borings locations.

Figure 5: Main prospect of the Cathedral.

Figure 6: Main prospect of the Collegiata Church.

Figure 7: Main prospect of the Stesicoro Church.

WIT Transactions on State of the Art in Science and Engineering, Vol 8, © 2005 WIT Press
www.witpress.com, ISSN 1755-8336 (on-line)

The shear waves velocity was evaluated by a simple estimation related to the soil nature given by boreholes or by empirical correlations between the results of *in situ* tests (mainly SPT and CPT tests) and shear waves velocity. According to Cavallaro *et al.* [8] the following correlations for SPT tests were used:
a) Ohta and Goto [10]:

$$V_S = 54.33 \cdot (N_{SPT})^{0.173} \cdot \alpha \cdot \beta \cdot \left( \frac{Z}{0.303} \right)^{0.193} \quad (1)$$

where: Vs = shear waves velocity (m/s), $N_{SPT}$ = number of blows SPT, Z = depth (m), α= age factor (Olocene = 1.000, Pleistocene = 1.303), β= geological factor (clay = 1.000, sand = 1.086).

b) Yoshida and Motonori [11]:

$$V_S = \beta \cdot (N_{SPT})^{0.25} \cdot \sigma_{v0}^{'0.14} \quad (2)$$

where: Vs = shear waves velocity (m/s), $N_{SPT}$ = number of blows SPT, Z = depth (m), $\sigma'_{vo}$= overburden pressure, β= geological factor (all soil = 55, fine sand = 49).

In a few cases, such as for the location of Saint Nicola alla Rena Church (Cavallaro *et al.* [8]), the estimation of shear waves velocity was checked by *in situ* dynamic tests: Down-Hole (DH) tests and by laboratory tests plus Resonant Column Tests (RCT) and Cyclic Loading Torsional Shear Tests (CLTST).

In addition the site and laboratory investigations, performed at some test sites and reported by Cavallaro and Maugeri [12] were considered.

For site response evaluation, the shear modulus at small strain ($G_0$) was evaluated by the following expression according to:

c) Jamiolkowski *et al.* [13]:

$$G_o = \frac{600 \cdot \sigma_m^{'0.5} p_a^{0.5}}{e^{1.3}} \quad (3)$$

where: $\sigma'_m = (\sigma'_v + 2 \cdot \sigma'_h)/3$; $p_a$ = 1 bar is a reference pressure; $G_O$, $\sigma'_m$ and $p_a$ are reported in the same unit.

The results obtained by (3) were checked with the $V_s$ measured by Down-Hole and Cross-Hole performed at test sites by means of the equation of elasticity: $G_o = \rho V_s^2$, where $\rho$ = mass density. The values of $G_0$ were also checked by the Resonant Column Tests (RCT) and by Cyclic Loading Torsional Shear Tests (CLTST). The results are quite often in good agreement (Cavallaro *et al.* [8]); sometime laboratory tests give lower values of $G_0$ than those obtained by *in situ* tests (Cavallaro *et al.* [9]).

RCT and CLTST performed at the test sites allow the measurement of the soil non-linearity which is very relevant for ground motion evaluation for the city of Catania (Grasso *et al.* [14]).

Soil non-linearity is taken into account by the following expressions according to Yokota *et al.* [15]:

$$\frac{G(\gamma)}{G_o} = \frac{1}{1 + \alpha\gamma(\%)^{\beta}}$$

$$D(\gamma)(\%) = \eta \cdot \exp\left[ -\lambda \cdot \frac{G(\gamma)}{G_o} \right] \quad (4)$$

in which: $G_0$ = initial shear modulus; $G(\gamma)$ = strain dependent shear modulus; $\gamma$ = shear strain; $\alpha$, $\beta$ = soil constants; $D(\gamma)$ = strain dependent damping ratio; $\eta$, $\lambda$ = soil constants.

For the clayey soil at the test site of via Stellata (Maugeri and Cavallaro [16]), the values are: $\alpha = 11$, $\beta = 1.119$, $\eta = 31$, $\lambda = 1.921$.

For the stiff soil at the site of Saint Nicola alla Rena Church (Cavallaro *et al.* [8]), the values are: $\alpha = 7.5$, $\beta = 0.897$, $\eta = 90$, $\lambda = 4.5$.

For the sandy soil at the test site of Piazza Palestro (Cavallaro and Maugeri [12]), the values are: $\alpha = 6.9$, $\beta = 1.0$, $\eta = 23$, $\lambda = 2.21$.

The unit weight $\gamma$ ranges between 18.3 and 20.5 $KN/m^{-3}$.

## 3 Site response analysis

The soil response analysis for the areas where the 108 Churches are located, has been performed by the 1-D non-linear code. As input earthquake at the bedrock we considered the scaled accelerograms of the December 13, 1990 Sicilian earthquake (M= 5.8), recorded at the Sortino Station located on rock.

The maximum acceleration recorded at Sortino E-W component was 1.005 $m/s^{-2}$. To simulate the scenario earthquake (M = 7.0), the maximum acceleration was increased up to 0.25 g, which was about the maximum acceleration recorded at the Catania station during the December 1990 earthquake. Also the frequency was scaled, increasing the period by a factor of 1.333, simulating that, for a big earthquake, there will be a bigger period. The scaled earthquake input was applied at a depth of 30 m, as recommended by EC8 (CEN [17]), or at a shallow depth, where there is a contrast of shear waves velocity.

Considering that the city of Catania has not so many topographic irregularities, a 1-D code was used. By the way, there are not so many differences using 1-D or 2-D codes (Grasso *et al.* [14]). More relevant in soil response evaluations are the soil properties and the soil non-linearity. Soil non-linearity was taken into account considering the decrease of initial shear modulus and increase of damping with shear strength, as reported in the previous paragraph.

The 1-D code (Frenna and Maugeri [18]) gives the time history of displacement, velocity and acceleration. The time history at the surface, as well as the response spectra, were evaluated at each site where the 108 Churches are located. In Table 1 are reported the time history of accelerations and the response spectra at each site. The results show that there is different site amplification from site to site and so different response spectra, which shows the possible damage for each Church in relation to the site where it is located. In Fig. 8 are reported the locations of the 108 churches, with the different hazard for each Church.

Table 1: Time history of accelerations with the response spectra at each site.

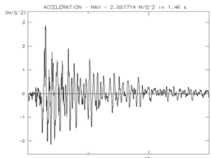
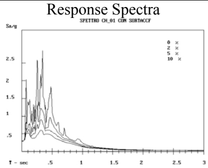
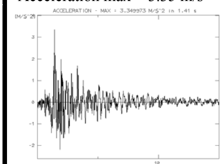
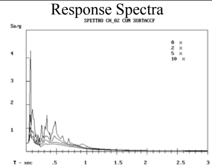
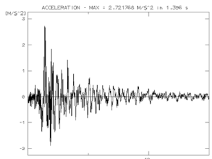
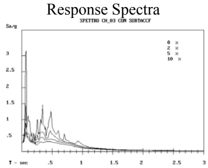
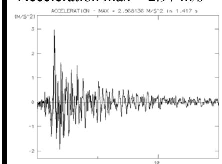
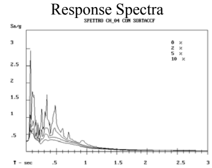
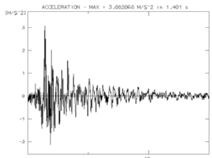
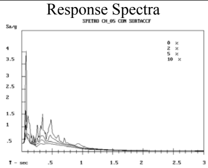
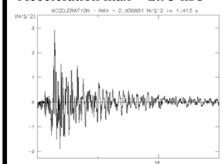
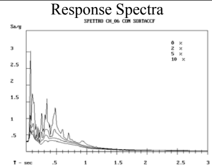
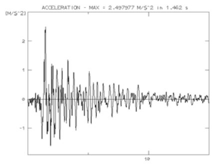
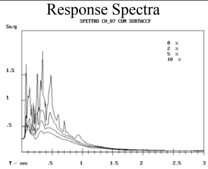
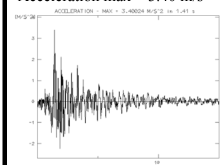
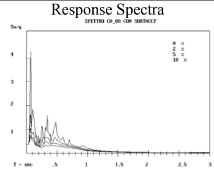
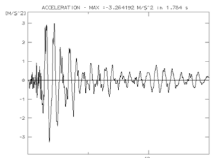
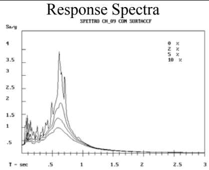
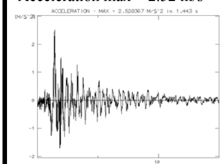
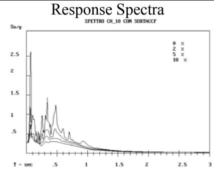
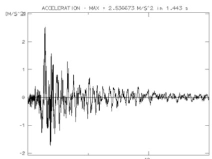
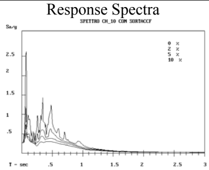
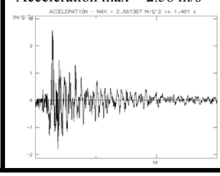
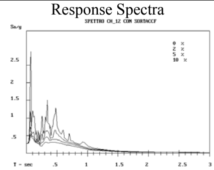
| | |
|---|---|
| **CHURCH 01** – *San Giovanni Battista in S.G. Galermo*,<br>Piazza Chiesa Madre | **CHURCH 02** – *S. Maria del Carmelo Barriera del Bosco*,<br>Piazza S.M. del Carmelo |
| Acceleration max = 2.88 $m/s^2$  Response Spectra  | Acceleration max = 3.35 $m/s^2$  Response Spectra  |
| **CHURCH 03** – *S. Stefano Primo Martire*,<br>Via Pelagie | **CHURCH 04** – *Santi Pietro e Paolo*,<br>Via Siena |
| Acceleration max = 2.72 $m/s^2$  Response Spectra  | Acceleration max = 2.97 $m/s^2$  Response Spectra  |
| **CHURCH 05** – *S. Cuore alla Barriera*,<br>Via del Bosco | **CHURCH 06** – *S. Maria del Carmelo al Canalicchio*,<br>Via Pietra dell'Ova |
| Acceleration max = 3.08 $m/s^2$  Response Spectra  | Acceleration max = 2.93 $m/s^2$  Response Spectra  |
| **CHURCH 07** – *S. Giovanni Apostolo ed Evangelista*,<br>Largo Gaspare Bertoni | **CHURCH 08** – *S.M. delle Grazie in Carruba di Ognina*,<br>Via Messina |
| Acceleration max = 2.50 $m/s^2$  Response Spectra  | Acceleration max = 3.40 $m/s^2$  Response Spectra  |
| **CHURCH 09** – *S. Maria di Nuovaluce*,<br>Via L. Lizio Bruno Monte Po | **CHURCH 10** – *Spirito Santo in Nesima Superiore*,<br>Via Pacinotti |
| Acceleration max = 3.26 $m/s^2$  Response Spectra  | Acceleration max = 2.52 $m/s^2$  Response Spectra  |
| **CHURCH 11** – *S. Pio X in Nesima Superiore*,<br>Piazza Santo Pio X | **CHURCH 12** – *Sacra Famiglia*,<br>Viale M. Rapisardi |
| Acceleration max = 2.54 $m/s^2$  Response Spectra  | Acceleration max = 2.58 $m/s^2$  Response Spectra  |

Table1: Continued.

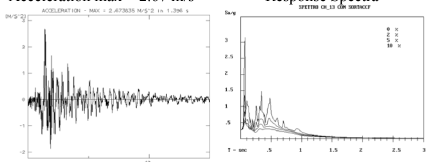
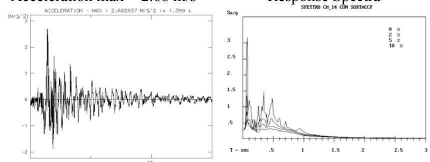
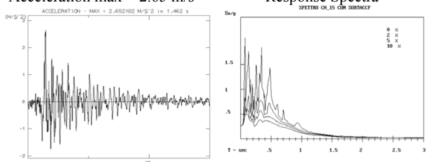
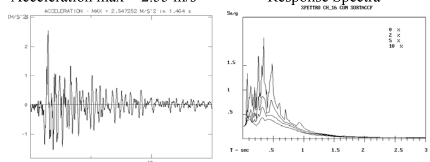
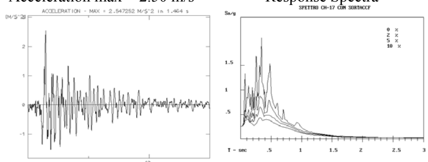
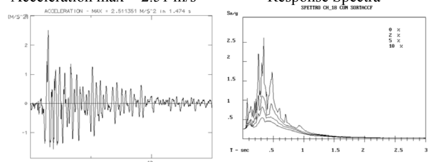
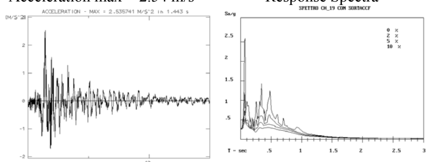
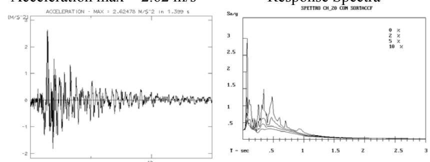
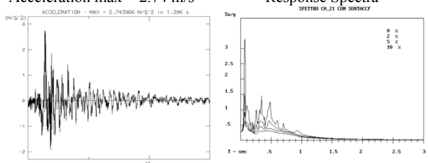
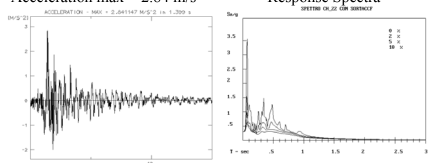
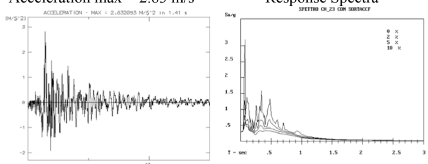
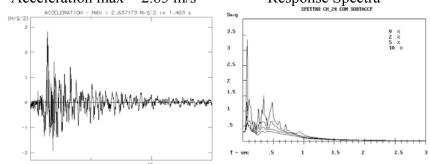
| | |
|---|---|
| **CHURCH 13** – *S. Michele Arcangelo*, Via Ota | **CHURCH 14** – *Natività del Signore*, Piazza Santa Maria Ausiliatrice |
| Acceleration max = 2.67 $m/s^2$ Response Spectra  | Acceleration max = 2.68 $m/s^2$ Response Spectra  |
| **CHURCH 15** – *Divina Maternità della B.V.M. in Cibali*, Piazza Bonadies | **CHURCH 16** – *S. Antonio*, Viale M. Rapisardi |
| Acceleration max = 2.65 $m/s^2$ Response Spectra  | Acceleration max = 2.55 $m/s^2$ Response Spectra  |
| **CHURCH 17** – *S. Giovanni Bosco*, Viale M. Rapisardi | **CHURCH 18** – *S. Maria di Gesù*, Piazza Santa Maria di Gesù |
| Acceleration max = 2.50 $m/s^2$ Response Spectra  | Acceleration max = 2.51 $m/s^2$ Response Spectra  |
| **CHURCH 19** – *S. Maria della Consolazione al Borgo*, Via Milo | **CHURCH 20** – *S.M. della Consolazione*, Via Consolazione |
| Acceleration max = 2.54 $m/s^2$ Response Spectra  | Acceleration max = 2.62 $m/s^2$ Response Spectra  |
| **CHURCH 21** – *S. Agata al Borgo*, Piazza Cavour | **CHURCH 22** – *SS. Sacramento al Borgo*, Piazza Cavour |
| Acceleration max = 2.74 $m/s^2$ Response Spectra  | Acceleration max = 2.84 $m/s^2$ Response Spectra  |
| **CHURCH 23** – *S. Maria di Monserrato*, Via Monserrato | **CHURCH 24** – *Nostra Sigmora di Lourdes*, Viale O. da Pordenone |
| Acceleration max = 2.83 $m/s^2$ Response Spectra  | Acceleration max = 2.83 $m/s^2$ Response Spectra  |

Table 1: Continued.

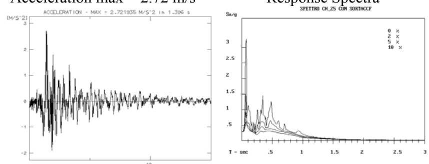
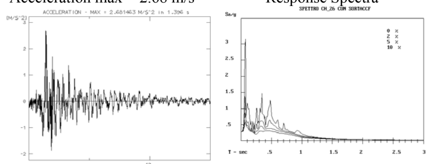
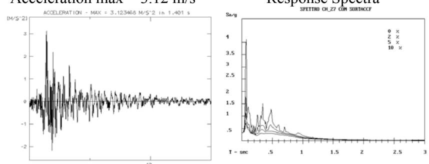
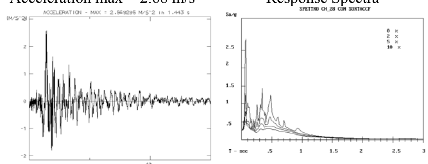
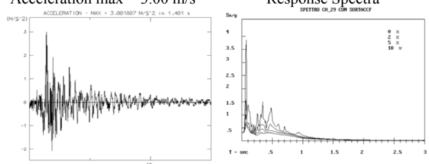
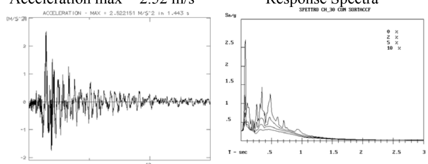
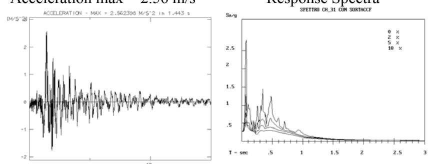
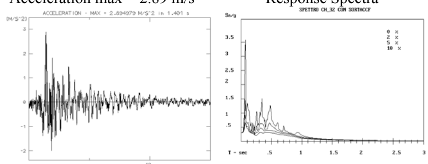
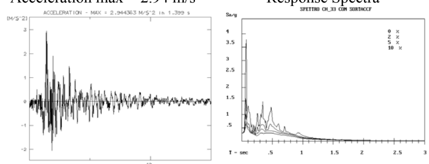
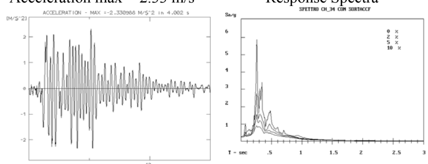
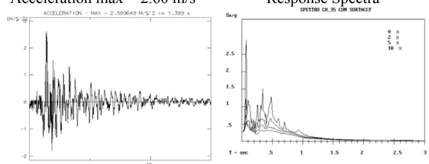
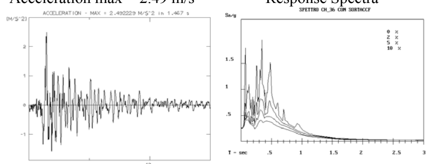
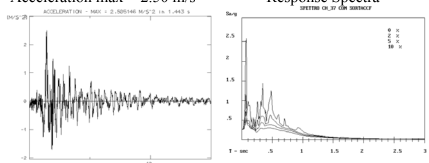
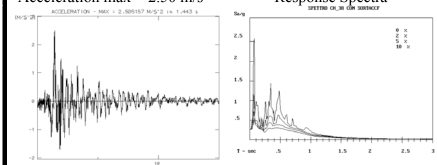
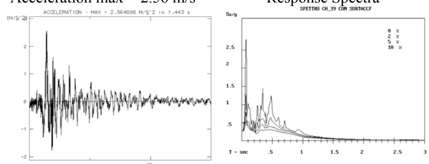
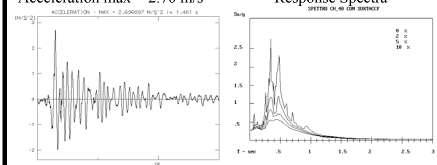
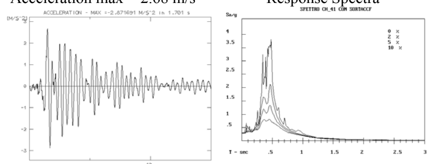
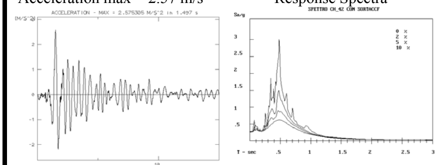
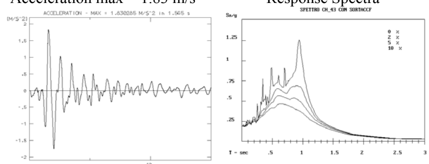
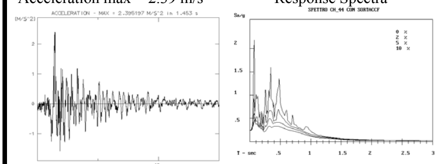
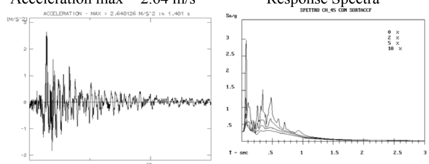
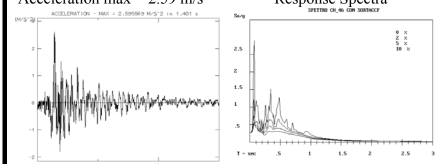
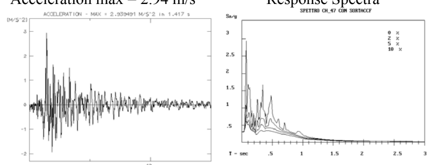
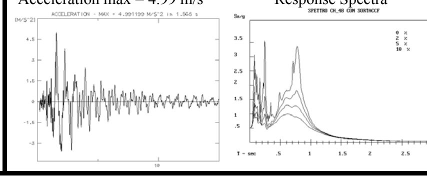
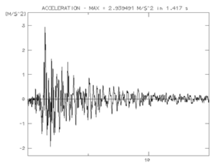
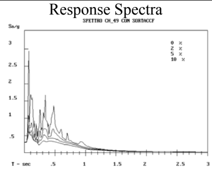
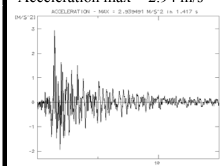
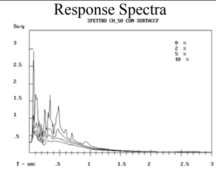
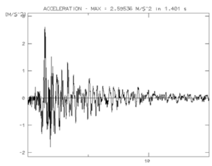
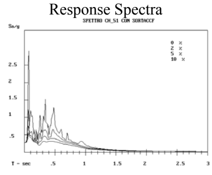
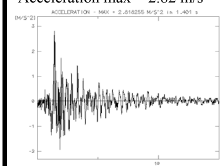
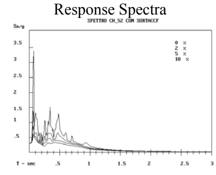
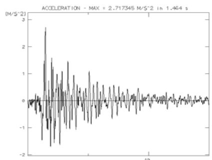
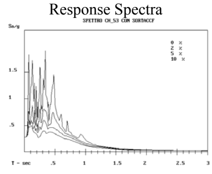
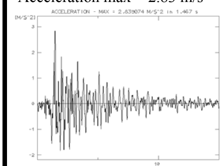
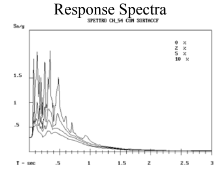
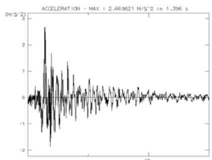
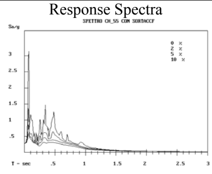
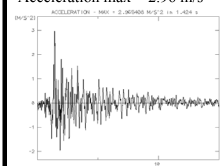
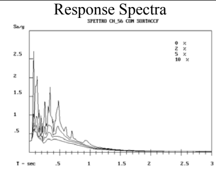
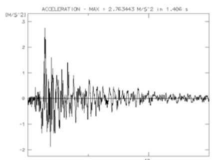
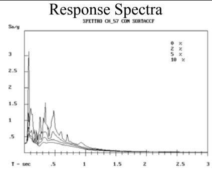
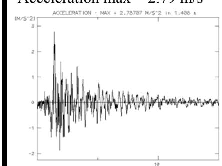
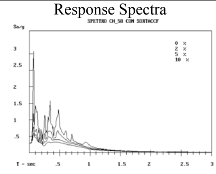
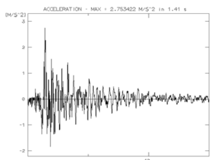
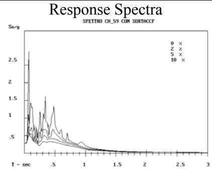
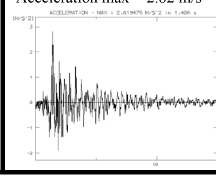
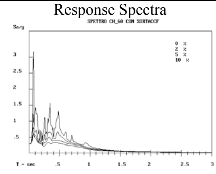
| | |
|---|---|
| **CHURCH 25** – *S. Domenico Savio*, Piazza S. Domenico Savio<br>Acceleration max = 2.72 $m/s^2$ Response Spectra<br> | **CHURCH 26** – *Cuore Immacolato della B.V.M. Picanello*, Viale V. Veneto<br>Acceleration max = 2.68 $m/s^2$ Response Spectra<br> |
| **CHURCH 27** – *S.M. della Salute in Picanello*, Piazza Madonna della Salute<br>Acceleration max = 3.12 $m/s^2$ Response Spectra<br> | **CHURCH 28** – *S. Lucia in Ognina*, Via Policastro<br>Acceleration max = 2.68 $m/s^2$ Response Spectra<br> |
| **CHURCH 29** – *S. Giuseppe in Ognina*, Via Grasso Finocchiaro<br>Acceleration max = 3.00 $m/s^2$ Response Spectra<br> | **CHURCH 30** – *S. Maria in Ognina*, Piazza Ognina<br>Acceleration max = 2.52 $m/s^2$ Response Spectra<br> |
| **CHURCH 31** – *Maris Stella*, Via Anapo<br>Acceleration max = 2.56 $m/s^2$ Response Spectra<br> | **CHURCH 32** – *S. Maria della Guardia in Ognina*, Via Zoccolanti<br>Acceleration max = 2.89 $m/s^2$ Response Spectra<br> |
| **CHURCH 33** – *Cristo Re*, Corso Italia<br>Acceleration max = 2.94 $m/s^2$ Response Spectra<br> | **CHURCH 34** – *S. Maria del Rosario in Nesima*, Via Monte Po<br>Acceleration max = 2.33 $m/s^2$ Response Spectra<br> |
| **CHURCH 35** – *S. Teresa del Bambino Gesù*, Corso Indipendenza<br>Acceleration max = 2.60 $m/s^2$ Response Spectra<br> | **CHURCH 36** – *S. Leone Vescovo*, Via S. Leone<br>Acceleration max = 2.49 $m/s^2$ Response Spectra<br> |

Table 1: Continued.

| | |
|---|---|
| **CHURCH 37** – *S. Luigi Gonzaga*, Viale M. Rapisardi | **CHURCH 38** – *S. Francesco di Paola*, Via Curia |
| Acceleration max = 2.50 $m/s^2$ Response Spectra  | Acceleration max = 2.50 $m/s^2$ Response Spectra  |
| **CHURCH 39** – S. *Cuore ai Cappuccini*, Via S.M. della Catena | **CHURCH 40** – *S. Cuore di Gesù al Fortino*, Piazza Palestro |
| Acceleration max = 2.56 $m/s^2$ Response Spectra  | Acceleration max = 2.70 $m/s^2$ Response Spectra  |
| **CHURCH 41** – *SS. Crocifisso Maiorana*, Piazza SS. Crocifisso Maiorana | **CHURCH 42** – *S. Bambino*, Via Plebiscito |
| Acceleration max = 2.68 $m/s^2$ Response Spectra  | Acceleration max = 2.57 $m/s^2$ Response Spectra  |
| **CHURCH 43** – *S. Euplio Martire*, Piazza M. Montessori | **CHURCH 44** – *S. Martino ai Bianchi*, Via V. Emanuele |
| Acceleration max = 1.83 $m/s^2$ Response Spectra  | Acceleration max = 2.39 $m/s^2$ Response Spectra  |
| **CHURCH 45** – *Santi Cosma e Damiano*, Piazza Machiavelli | **CHURCH 46** – *S. Domenico*, Piazza S. Domenico |
| Acceleration max = 2.64 $m/s^2$ Response Spectra  | Acceleration max = 2.59 $m/s^2$ Response Spectra  |
| **CHURCH 47** – *S. Vito*, Piazza S. Domenico | **CHURCH 48** – *senza nome*, Via Plebiscito |
| Acceleration max = 2.94 $m/s^2$ Response Spectra  | Acceleration max = 4.99 $m/s^2$ Response Spectra  |


www.witpress.com, ISSN 1755-8336 (on-line)

Table 1: Continued.

| | |
|---|---|
| **CHURCH 49** – *S. Agata la Vetere*, Via S. Maddalena | **CHURCH 50** – *S. Agata al Carcere*, Piazza Santo Carcere |
| Acceleration max = 2.94 m/s$^2$  Response Spectra  | Acceleration max = 2.94 m/s$^2$  Response Spectra  |
| **CHURCH 51** – *S. Biagio*, Piazza Stesicoro | **CHURCH 52** – *S.M. della Purità*, Via S. Maddalena |
| Acceleration max = 2.60 m/s$^2$  Response Spectra  | Acceleration max = 2.82 m/s$^2$  Response Spectra  |
| **CHURCH 53** – *S. Camillo*, Via Crociferi | **CHURCH 54** – *S. Michele ai Minoriti*, Via Etnea |
| Acceleration max = 2.72 m/s$^2$  Response Spectra  | Acceleration max = 2.83 m/s$^2$  Response Spectra  |
| **CHURCH 55** – *Immacolata Concezione ai Minoriti*, Via G. Clementi | **CHURCH 56** – *S. Nicolò all'Arena*, Piazza Dante |
| Acceleration max = 2.67 m/s$^2$  Response Spectra  | Acceleration max = 2.96 m/s$^2$  Response Spectra  |
| **CHURCH 57** – *S. Giuliano*, Via Crociferi | **CHURCH 58** – *S. Francesco Borgia*, Via Crociferi |
| Acceleration max = 2.76 m/s$^2$  Response Spectra  | Acceleration max = 2.79 m/s$^2$  Response Spectra  |
| **CHURCH 59** – *S. Benedetto*, Via Crociferi | **CHURCH 60** – *Santo Sacramento al Duomo*, Via Biscari |
| Acceleration max = 2.75 m/s$^2$  Response Spectra  | Acceleration max = 2.82 m/s$^2$  Response Spectra  |


www.witpress.com, ISSN 1755-8336 (on-line)

Table 1: Continued.

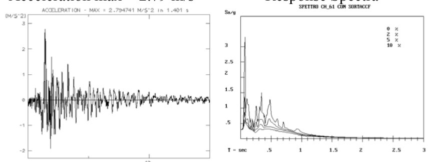
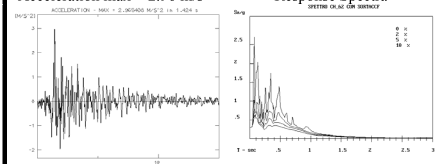
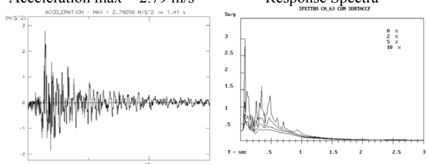
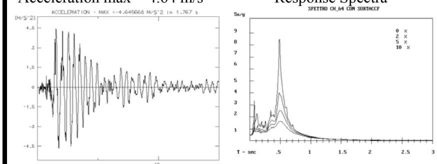
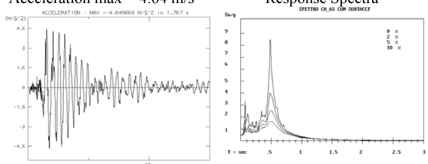
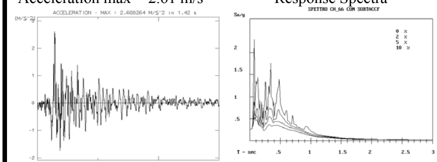
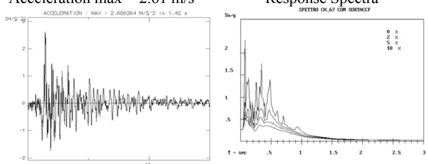
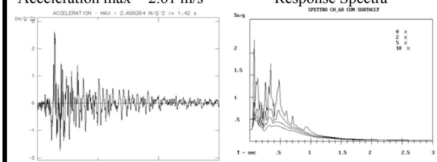
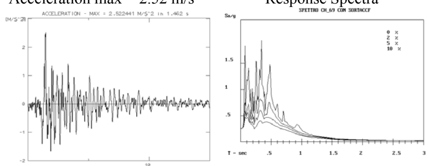
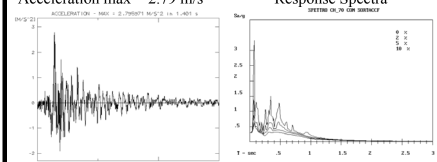
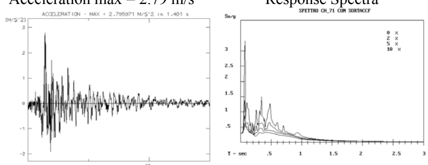
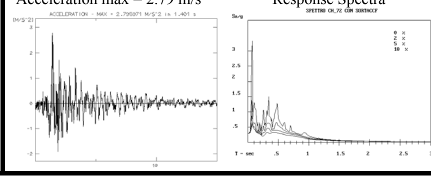
| | |
|---|---|
| **CHURCH 61** – *Basilica Collegiata S.M. della Elemosina*, Via Etnea | **CHURCH 62** – *S. Filippo Neri*, Via Teatro Greco |
| Acceleration max = 2.79 m/s$^2$ Response Spectra  | Acceleration max = 2.96 m/s$^2$ Response Spectra  |
| **CHURCH 63** – *S. Agata*, Via Teatro Greco | **CHURCH 64** – *SS. Trinità*, Via V. Emanuele |
| Acceleration max = 2.79 m/s$^2$ Response Spectra  | Acceleration max = 4.64 m/s$^2$ Response Spectra  |
| **CHURCH 65** – *S. Agostino*, Via V. Emanuele | **CHURCH 66** – *S. Francesco d'Assisi*, Piazza S. Francesco |
| Acceleration max = 4.64 m/s$^2$ Response Spectra  | Acceleration max = 2.61 m/s$^2$ Response Spectra  |
| **CHURCH 67** – *S. Giuseppe al Duomo*, Via V. Emanuele | **CHURCH 68** – *S. Agata alle Sciare*, Via V. Emanuele |
| Acceleration max = 2.61 m/s$^2$ Response Spectra  | Acceleration max = 2.61 m/s$^2$ Response Spectra  |
| **CHURCH 69** – *Cattedrale di S. Agata V.M.*, Via V. Emanuele | **CHURCH 70** – *S. Agata Badia*, Via V. Emanuele |
| Acceleration max = 2.52 m/s$^2$ Response Spectra  | Acceleration max = 2.79 m/s$^2$ Response Spectra  |
| **CHURCH 71** – *Monastero di S. Agata*, Via V. Emanuele | **CHURCH 72** – *S. Placido*, Piazza S. Placido |
| Acceleration max = 2.79 m/s$^2$ Response Spectra  | Acceleration max = 2.79 m/s$^2$ Response Spectra  |

Table 1: Continued.

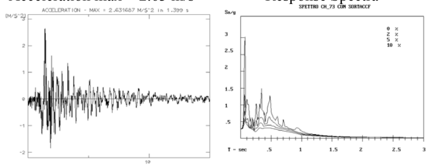
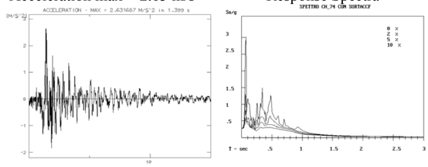
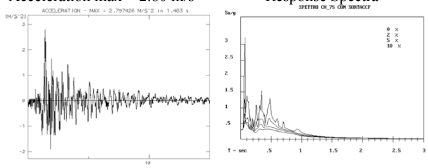
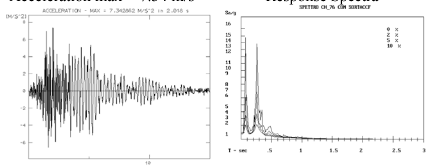
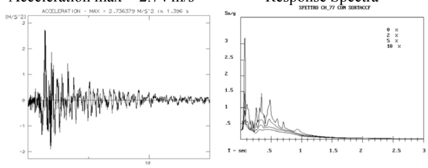
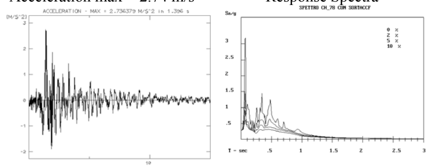
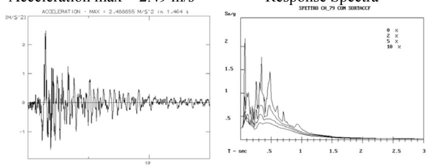
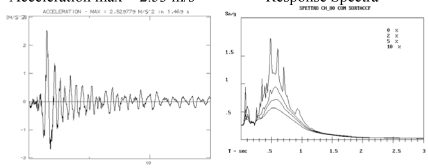
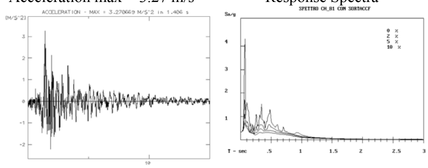
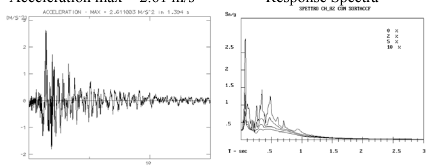
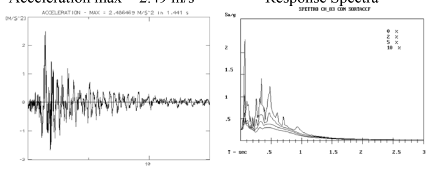
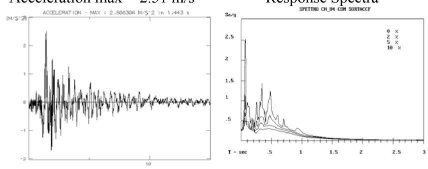
| | |
|---|---|
| **CHURCH 73** – *S. Orsola*, Piazza Scammacca | **CHURCH 74** – *S. Maria di Ogninella*, Piazza Ogninella |
| Acceleration max = 2.63 $m/s^2$ Response Spectra  | Acceleration max = 2.63 $m/s^2$ Response Spectra  |
| **CHURCH 75** – *S. Teresa*, Via A. Sangiuliano | **CHURCH 76** – *S.M. della Concordia*, Via S. Euplio |
| Acceleration max = 2.80 $m/s^2$ Response Spectra  | Acceleration max = 7.34 $m/s^2$ Response Spectra  |
| **CHURCH 77** – *S. Maria della Mercede*, Via Caronda | **CHURCH 78** – *S. Caterina al Rinazzo*, Via Umberto |
| Acceleration max = 2.74 $m/s^2$ Response Spectra  | Acceleration max = 2.74 $m/s^2$ Response Spectra  |
| **CHURCH 79** – *Basilica SS. Crocifisso dei Miracoli*, Via Umberto | **CHURCH 80** – *Maria SS. Annunziata al Carmine*, Via G. Verdi |
| Acceleration max = 2.49 $m/s^2$ Response Spectra  | Acceleration max = 2.53 $m/s^2$ Response Spectra  |
| **CHURCH 81** – *S. Berillo in S.M. degli Ammalati*, Piazza G. Bovio | **CHURCH 82** – *S. Gaetano alle Grotte*, Via S. Gaetano alle Grotte |
| Acceleration max = 3.27 $m/s^2$ Response Spectra  | Acceleration max = 2.61 $m/s^2$ Response Spectra  |
| **CHURCH 83** – *SS. Crocifisso della Buona Morte*, Piazza G. Falcone | **CHURCH 84** – *SS. Sacramento Ritrovato*, Via VI Aprile |
| Acceleration max = 2.49 $m/s^2$ Response Spectra  | Acceleration max = 2.51 $m/s^2$ Response Spectra  |

Table 1: Continued.

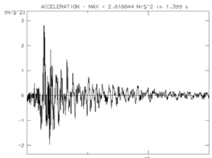
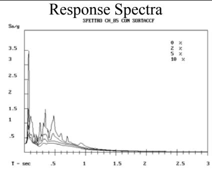
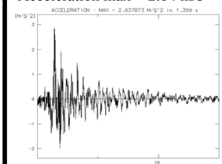
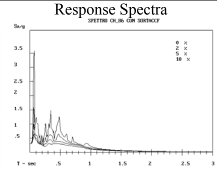
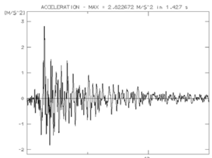
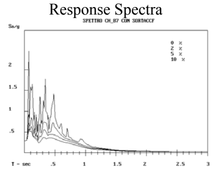
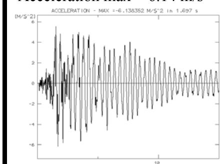
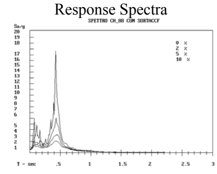
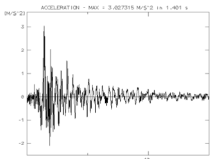
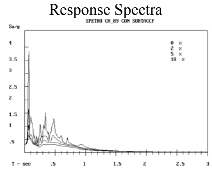
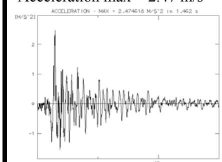
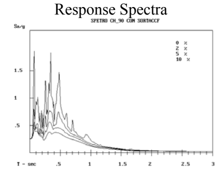
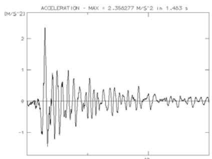
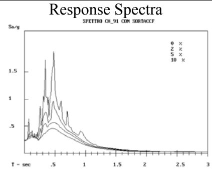
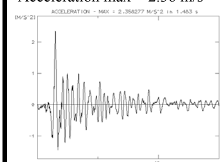
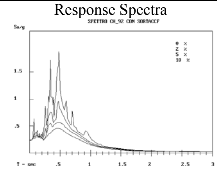
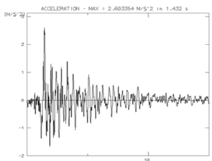
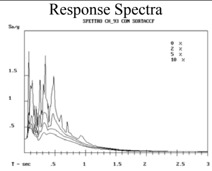
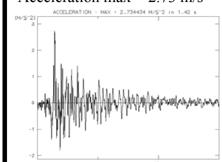
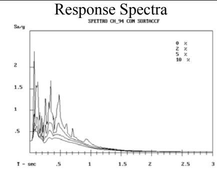
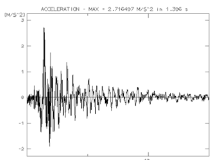
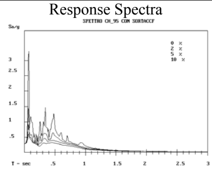
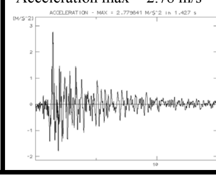
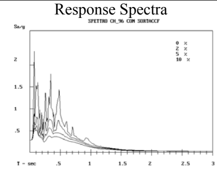
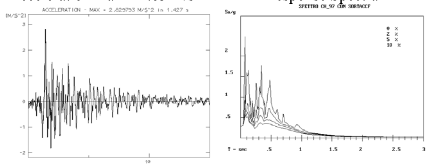
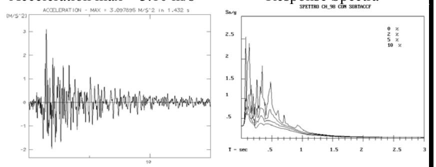
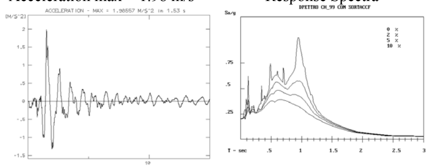
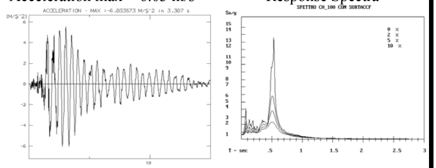
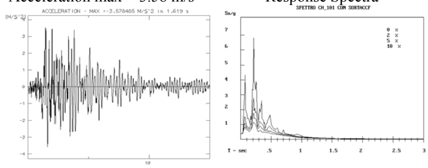
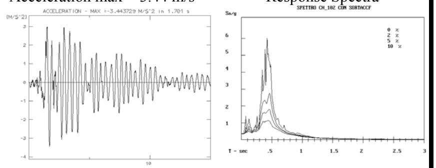
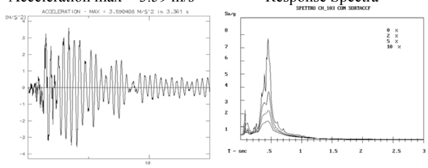
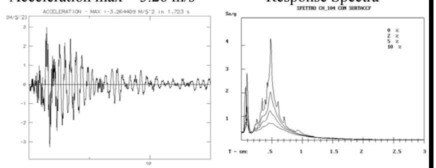
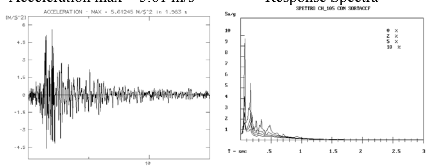
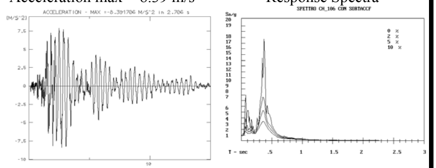
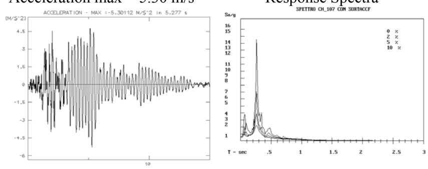
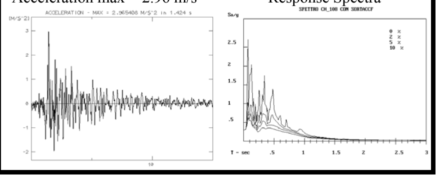
| | |
|---|---|
| **CHURCH 85** – *S. Gaetano alla Marina*, Via S. Gaetano | **CHURCH 86** – *S. Francesco di Paola*, Piazza S. Francesco di Paola |
| Acceleration max = 2.82 $m/s^2$  Response Spectra  | Acceleration max = 2.84 $m/s^2$  Response Spectra  |
| **CHURCH 87** – *S. Maria dell'Indirizzo*, Piazza Currò | **CHURCH 88** – *S. Lucia al Fortino*, Via Gismondo |
| Acceleration max = 2.82 $m/s^2$  Response Spectra  | Acceleration max = 6.14 $m/s^2$  Response Spectra  |
| **CHURCH 89** – *S. Cristoforo alle Sciare*, Via Plebiscito | **CHURCH 90** – *S. Maria dell'Aiuto*, Via Consolato della Seta |
| Acceleration max = 3.03 $m/s^2$  Response Spectra  | Acceleration max = 2.47 $m/s^2$  Response Spectra  |
| **CHURCH 91** – *S. Giuseppe al Transito*, Piazza Maravigna | **CHURCH 92** – *S. Sebastiano*, Piazza Federico di Svevia |
| Acceleration max = 2.36 $m/s^2$  Response Spectra  | Acceleration max = 2.36 $m/s^2$  Response Spectra  |
| **CHURCH 93** – *S. Chiara*, Via Garibaldi | **CHURCH 94** – *Santi Angeli Custodi*, Via S. Angelo Custode |
| Acceleration max = 2.60 $m/s^2$  Response Spectra  | Acceleration max = 2.73 $m/s^2$  Response Spectra  |
| **CHURCH 95** – *S. Maria della Salette*, Via S.M. della Salette | **CHURCH 96** – *Cappella Votiva S.M. delle Grazie*, Via S.M. delle Grazie |
| Acceleration max = 2.72 $m/s^2$  Response Spectra  | Acceleration max = 2.78 $m/s^2$  Response Spectra  |

Table 1: Continued.

| | |
|---|---|
| **CHURCH 97** – *S. Anna*, Via S. Anna | **CHURCH 98** – *B.V. Maria in Cielo Assunta alla Plaia*, Piazza Caduti del Mare |
| Acceleration max = 2.83 m/s$^2$ Response Spectra  | Acceleration max = 3.10 m/s$^2$ Response Spectra  |
| **CHURCH 99** – *Chiesa della Risurrezione*, Cimitero Monumentale | **CHURCH 100** – *S. Maria Ausiliatrice e S. Domenico Savio*, Stradale S. Giorgio |
| Acceleration max = 1.98 m/s$^2$ Response Spectra  | Acceleration max = 6.03 m/s$^2$ Response Spectra  |
| **CHURCH 101** – *B.M.V. del Carmelo e S.M. Goretti in S. Giorgio*, Via dell'Idris | **CHURCH 102** – *S. Chiara in Librino*, Viale Monacale |
| Acceleration max = 3.58 m/s$^2$ Response Spectra  | Acceleration max = 3.44 m/s$^2$ Response Spectra  |
| **CHURCH 103** – *Nostra Signora del SS. Sacramentro in Librino*, Via delle Susine | **CHURCH 104** – *Risurrezione del Signore*, Via Castagnola |
| Acceleration max = 3.59 m/s$^2$ Response Spectra  | Acceleration max = 3.26 m/s$^2$ Response Spectra  |
| **CHURCH 105** – *Madonna del Divino Amore in Zia Lisa*, Via Zia Lisa | **CHURCH 106** – *S. Giuseppe al Pigno*, Via delle Clementine |
| Acceleration max = 5.61 m/s$^2$ Response Spectra  | Acceleration max = 8.39 m/s$^2$ Response Spectra  |
| **CHURCH 107** – *S. Giuseppe la Rena*, Via S. Giuseppe la Rena | **CHURCH 108** – *Madonna dell'Idra*, Via Idra |
| Acceleration max = 5.30 m/s$^2$ Response Spectra  | Acceleration max = 2.96 m/s$^2$ Response Spectra  |

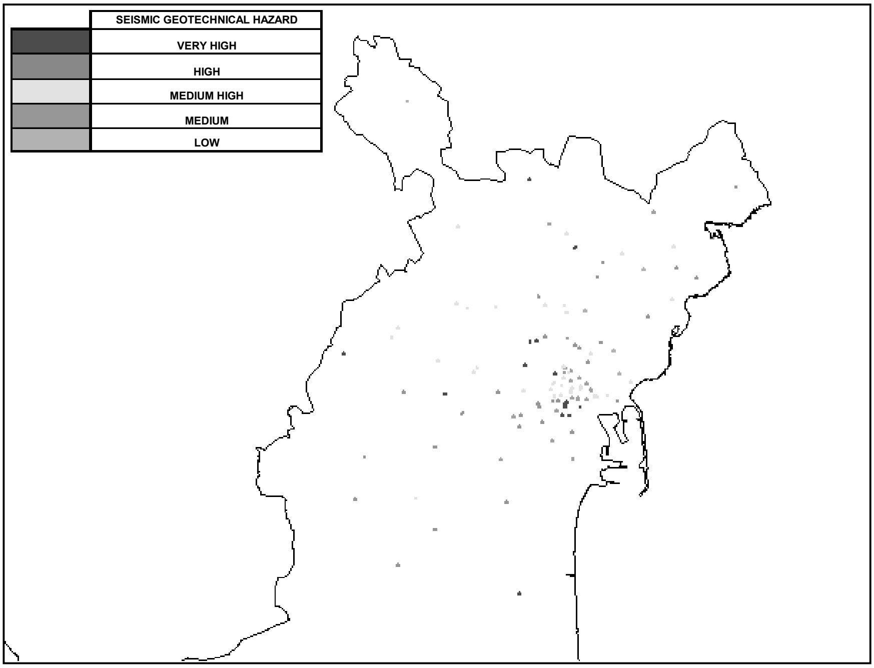



Figure 8: Locations of the 108 Churches, with the different seismic geotechnical hazard for each Church.

## 4 Conclusions

The seismic protection of the monuments located in Mediterranean cities is one of the main tasks to be achieved in the city of Catania. To this aim, the seismic hazard must be evaluated on the basis of an accurate site characterization of the areas where the churches are located. In some cases detailed site characterization was performed; in other cases the site characterization was reached by a query to the GIS database, including geology, borings and geotechnical soil properties. The site effects were evaluated by a 1-D code which takes into account soil non-linearity. The results show that seismic hazard changes very much from site to site. The soil response given for each church could be used to evaluate the design spectra, which can be used for the structural improvement of the Churches to resist against the earthquake scenario.

## References

[1] Maugeri, M. (2000). Detailed Scenarios and actions for seismic prevention of damage in the urban area of Catania. Framework Program 2000-2002 of the National Group for the Defence Against Earthquakes

(National Group of Geophysics and Volcanology), financed by the Department of Civil Defence, June 2000.
[2] Cherubini, A., Cocina, S. & Lagomarsino, S. (2000). Survey of old Churches. In: *The Catania Project: Earthquake Damage Scenarios for a high risk area in the Mediterranean.* Editors: Faccioli and Pessina. CNR-Gruppo Nazionale per la difesa dai terremoti-Roma 2000, pp. 105-110.
[3] Priolo, E. (1999). 2-D spectral element simulations of destructive ground shaking in Catania (Italy*). J. of Seismology,* 3(3), 289-309.
[4] Laurenzano G. & Priolo E. (2004). Numerical modeling of the December 13, 1990 M = 5.8 eastern Sicily earthquake. Workshop on: *Detailed Scenarios and Actions for Seismic Prevention of Damage in the Urban Area of Catania,* Catania, 9-10 January, 2003.
[5] Grasso S. & Maugeri M. (2004). Vulnerability of physical environment of the city of Catania using GIS technique. Workshop on: *Detailed Scenarios and Actions for Seismic Prevention of Damage in the Urban Area of Catania,* Catania, 9-10 January, 2003.
[6] Monaco, C., Catalano, S., De Guidi, G. & Tortorici, L. (2004). The Geological map of the urban area of Catania (Eastern Sicily). Workshop on: *Detailed Scenarios and Actions for Seismic Prevention of Damage in the Urban Area of Catania,* Catania, 9-10 January, 2003.
[7] Grasso, S. & Maugeri, M. (2003). A GIS Model Application Supporting the Analysis of the Seismic Hazard for the Urban Area of Catania (Italy). *Proc. of the XIII European Conference on Soil Mechanics and Geotechnical Engineering, Geotechnical Problems with Man-made and Man Influenced Grounds*, Prague, August 25-28, 2003, vol. 2, 941-946.
[8] Cavallaro, A., Grasso, S. & Maugeri, M. (2001). A dynamic geotechnical characterization of soil at Saint Nicola alla Rena Church site damaged by the southeastern Sicily earthquake of 13 December 1990. *XV International Conference on Soil Mechanics and Geotechnical Engineering: Lessons Learned from Recent Strong Earthquakes. Earthquake Geotechnical Engineering Satellite Conference*, Istanbul, Turkey, August 24, 2001.
[9] Cavallaro, A., Grasso, S. & Maugeri, M. (2001). Geotechnical parameters for the seismic geotechnical hazard evaluation for the urban area of Catania. *X Italian Conference on Seismic Engineering*, Potenza-Matera, Italy, 9-13 September, 2001 (in Italian).
[10] Ohta, Y. & Goto, N. (1978). Empirical shear wave velocity equations in terms of characteristic soil indexes. *Earthquake Engineering and Structural Dynamics*,Vol. 6.
[11] Yoshida, Y. & Motonori, I. (1988). Empirical formulas of SPT blow-counts for gravelly soils. *Proceedings of ISOPT-1*, Orlando (USA).
[12] Cavallaro, A. & Maugeri M. (2004). Non linear behaviour of the soil of the city of Catania at the test sites. Workshop on: *Detailed Scenarios and Actions for Seismic Prevention of Damage in the Urban Area of Catania,* Catania, 9-10 January, 2003.
[13] Jamiolkowski, M., Lo Presti, D.C.F. & Pallara, O. (1995). Role of in-situ testing in geotechnical earthquake engineering. *Third International*

*Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*, State of the Art 7, Vol. 3, pp. 1523-1546.

[14] Grasso, S., Laurenzano, G., Maugeri, M. & Priolo, E. (2004). Seismic response in Catania by different methodologies. Workshop on: *Detailed Scenarios and Actions for Seismic Prevention of Damage in the Urban Area of Catania,* Catania, 9-10 January, 2003.

[15] Yokota, K., Imai, T. & Konno, M. (1981). Dynamic deformation characteristics of soils determined by laboratory tests. *OYO Tec*. Rep. 3, pp. 13-37.

[16] Maugeri, M. & Cavallaro, A. (2000). Non linear soil behaviour of Catania clays. In: *The Catania Project: Earthquake Damage Scenarios for a High Risk Area in the Mediterranean.* Editors: Faccioli and Pessina. CNR-Gruppo Nazionale per la difesa dai terremoti-Roma 2000, pp. 38-41.

[17] CEN (2002). Design of Structures for Earthquake Resistance. Part 1: General Rules, seismic actions and rules for buildings. Draft No. 5, Revised Final Project Team Draft (Prestage 49). Brussels: European Committee for Standardization (CEN), May 2002, 197 pp.

[18] Frenna, S.M. & Maugeri, M. (1995). GEODIN: a Computer Code for Seismic Soil Response. *Proceedings of the 9th Italian Conference on Computational Mechanics*. Catania, Italy, 20-22 June, (in Italian), pp. 145-148.