Stretto di Messina

Concessionaria per la progettazione, realizzazione e gestione del collegamento stabile tra la Sicilia e il Continente Organismo di Diritto Pubblico
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Eurolink

PONTE SULLO STRETTO DI MESSINA

PROGETTO DEFINITIVO

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1 Introduction

Scope of this document is to summarize the results of the study "Definition of Seismic Actions for the Messina Strait Bridge" of June 12, 2010 (/1/) and summarize the practical guidelines for the design. Design indications relate to the definition of the magnitude of seismic actions on the reference ground to be used for the analyses of the Messina Strait Crossing and the criteria to take into account the effects of local amplification and three-dimensionality of the ground motion. Data supplied are in compliance and completion of the indications supplied by the Italian Standards (/1/ Technical Standards for Constructions, Ministry Decree of 14/1/2008), European Standards (/2/ Eurocode 8, 1998-1, Design of structures for earthquake resistance design Part 2: General rules, seismic actions and rules for buildings, /3/ Eurocode 8, 1998-2, Design of structures for earthquake resistance design Part 2: Bridges) and AASHTO Standards (/4/ AASHTO Guide Specifications for LRFD Seismic Bridge Design).

2 Seismic Action

The design seismic action for the Suspension Bridge is precautionarily not lower than that provided by the reference National Seismic Hazard, as implemented in the Italian Standards (/1/), and is derived from the study of documents GCG.F.04.01 of 1992 and DT.ISP.S.E.R1.001 of 2004 and of 27 set of accelerometric recordings opportunely selected, as explained in detail in document "Definition of Seismic Actions for the Messina Strait Bridge" of June 12, 2010 (/5/). The choice of the recordings that can be used for the definition of the design seismic action involved the following activities:

1. Evaluation of potential seismic sources for the site and possible seismo-genetic attributes, both general derived from literature data (e.g. magnitude, distance from epicentre, depth of hypocentre, directionality, type of the generative mechanism), and of more direct interest to the design (e.g. accelerations and frequency content).

2. Identification, in the databases available nationally and internationally, of a set of accelerograms recorded on bedrock, for seismic events with attributes similar to those determined in item 1.

3. Analysis of the reliability of recordings identified under item 2 to verify the correctness of the content in frequency, in association with the accuracy of the relevant measuring systems,

with specific reference to the long period areas of special interest for the Suspension Bridge.

As a result of these activities, 27 seismic events have been identified. Three accelerometric recordings have been considered for each of them, two for the horizontal components and one for the vertical component of the ground motion (Tables 2.1 and 2.2).

Table 2.1 Summary of seismic events obtained from PEER database

Record Sequence Number	Earthquake Name	Station Name	YEAR	Earthquake Magnitude (Mw)	Campbell R Dist. (km)	Preferred NEHRP based on Vs30	Preferred Vs30 (m/s)	PGA (g)
1	Parkfield	Temblor pre-1969	1966	6.19	16.24	C	527.9	0.29
2	San Fernando	Pacoima Dam (upper left abut)	1971	6.61	3.03	A	2016.1	1.16
3	Morgan Hill	Coyote Lake Dam (SW Abut)	1984	6.19	3.01	C	597.1	0.97
4	Morgan Hill	Gilroy Array #6	1984	6.19	10.30	C	663.3	0.28
5	Loma Prieta	Gilroy - Gavilan Coll.	1989	6.93	9.96	C	729.7	0.33
6	Loma Prieta	Gilroy Array #1	1989	6.93	9.64	B	1428.0	0.44
7	Loma Prieta	LGPC	1989	6.93	3.88	C	477.7	0.78
8	Landers	Lucerne	1992	7.28	3.71	C	684.9	0.72
9	Northridge-01	LA Dam	1994	6.69	5.92	C	629.0	0.45
10	Northridge-01	Pacoima Dam (downstr)	1994	6.69	7.01	A	2016.1	0.41
11	Northridge-01	Pacoima Dam (upper left)	1994	6.69	7.01	A	2016.1	1.43
12	Kobe, Japan	KJMA	1995	6.90	3.23	D	312.0	0.71
13	Kobe, Japan	Nishi-Akashi	1995	6.90	8.12	C	609.0	0.49
14	Kocaeli, Turkey	Arcelik	1999	7.51	13.52	C	523.0	0.17
15	Kocaeli, Turkey	Gebze	1999	7.51	10.98	B	792.0	0.18
16	Cape Mendocino	Petrolia	1992	7.01	8.18	C	712.8	0.62
17	Northridge-01	Burbank - Howard Rd.	1994	6.69	16.88	B	821.7	0.14
18	Northridge-01	LA - Chalon Rd	1994	6.69	20.45	C	740.1	0.21
19	Northridge-01	LA - Griffith Park Observatory	1994	6.69	23.77	B	1015.9	0.25
20	Northridge-01	LA - Wonderland Ave	1994	6.69	20.30	B	1222.5	0.13
21	Northridge-01	LA 00	1994	6.69	19.07	C	706.2	0.32
22	Northridge-01	Santa Susana Ground	1994	6.69	16.74	C	715.1	0.25

Table 2.2 Summary of seismic events obtained from Itaca data base (http://itaca.mi.ingv.it)

Record Sequence Number	Earthquake Name	Station Name	YEAR	Earthquake Magnitude (Mw)	R epi. [km]	Site Class EC8	PGA (g)
23	L'Aquila Mainshock	AQV	2009	6.3	4.87	B	0.65
24	L'Aquila Mainshock	AQK	2009	6.3	5.65	B	0.36
25	L'Aquila Mainshock	AQG	2009	6.3	4.39	B	0.49
26	L'Aquila Mainshock	AQA	2009	6.3	4.63	B	0.44
27	L'Aquila Mainshock	AQU	2009	6.3	6.02	B	0.31

These accelerometric recordings, opportunely homogenized through the use of damping laws, have been used for the definition of ground motion parameters, i.e. the maximum acceleration, velocity and displacement values, denoted as **P**eak **G**round **A**cceleration (**PGA**), **P**eak **G**round **V**elocity (**PGV**) and **P**eak **G**round **D**isplacement (**PGD**) respectively and of the response spectra expected at site for damping ratios equal to ξ=5% and to ξ=2%. The so-defined ground motion parameters and response spectra are to be considered referred to the reference subsoil, i.e. to a Type A stratigraphy, as defined in the Italian Standards (Technical Standards for Constructions NTC08, Ministry Decree of 14/1/2008, Suppl. ord. no. 30 to Official Bulletin no. 29 of 4/2/2008.) and in the European Standards (/2/), and to a horizontal topographic surface.

2.1 Seismicity of the Area

For the purposes of the design of the Messina Strait Bridge, the seismic hazard of the site is described in terms of 3 ground motion parameters, i.e. the maximum acceleration, velocity and displacement values indicated as PGA, PGV and PGD respectively.

The value of the provided ground motion parameters correspond to the maximum seismic event expected at the site, for which the collapse prevention performance requirement must be guaranteed. Said values are:

1. not lower than the values of the reference national seismic hazard, as considered in the Italian Standards (Technical Standards for Constructions NTC08, Ministry Decree of 14/1/2008, Suppl. ord. no. 30 to Official Bulletin no. 29 of 4/2/2008.);
2. not lower than the average values derived from the records;
3. in mutual ratios between the components equal to the average ratios found in the records.

The motion parameters so defined show characteristics compatible with those detected on real seismic events and are precautionary as for the Italian standards in force. Values for the horizontal main (H_{max}), secondary (H_{min}) and vertical (V) motion components are indicated in Table 2.3.

Table 2.3 Parameters of ground motion for horizontal H_{max}, H_{min} and vertical V components

Parameter	H_{max}	H_{min}	V
PGA (g)	0.50	0.34	0.45
PGV (cm/s)	60.00	20.67	14.77
PGD (cm)	25.00	8.03	5.17

2.2 Basic Representation of the Seismic Action

In this document, the seismic event at a given point of the surface is represented is represented by an elastic acceleration response spectrum. In abbreviations, acceleration, velocity and spectral displacements are identified as **S**pectral **A**cceleration (**SA**), **S**pectral **V**elocity (**SV**) and **S**pectral **D**isplacement (**SD**), respectively and the relevant maximum values as **P**eak **S**pectral **A**cceleration (**PSA**), **P**eak **S**pectral **V**elocity (**PSV**) and **P**eak **S**pectral **D**isplacement (**PSD**). The shape of the elastic response spectrum is defined by the following seven expressions relating to the seven sections in which the spectrum is divided:

T=	$0s \div T_A$	SA=	PGA		SA=cost.=PGA
T=	$T_A \div T_B$	SA=	$PGA \times [1+(F_a-1) \times (T-T_A) / (T_B-T_A)]$		SA=PGA→ PSA
T=	$T_B \div T_C$	SA=	$PGA \times F_a$		SA=cost.=PSA
T=	$T_C \div T_D$	SA=	$PGV \times F_v \times 2\pi / T$		SV=cost.=PSV
T=	$T_D \div T_E$	SA=	$PGD \times F_d \times (2\pi / T)^2$		SD=cost.=PSD
T=	$T_E \div T_F$	SA=	$PGD \times [F_d-(F_d-1) \times (T-T_E) / (T_F-T_E)] \times (2\pi / T)^2$		SD=PSD→PGD

$T > T_F$ SA= $PGD \times (2\pi / T)^2$ SD=cost.=PGD

In the expressions, F_a, F_v and F_d are the dynamic amplification factors, relating to acceleration, velocity and displacements respectively, and T_A, T_B, T_C, T_D, T_E, T_F are the six characteristic oscillation periods (separating one and another of the seven sections) of the response spectrum. The values of the amplification factors and of the characteristic oscillation periods, together with the ground motion parameters given in § 2.1, contribute to the definition of the response spectra for the maximum seismic event expected at site, on reference subsoil, for which the collapse prevention performance requirement must be guaranteed. The y-axis of the response spectra for the three motion components result:

1. not lower than the values obtained from the reference national seismic hazard, as considered in the Italian Standards (/1/);
2. not lower than the average values obtained from the recordings;
3. in mutual ratios between the components equal to the average ratios found in the records.

The response spectra so defined show characteristics compatible to what detected in actual seismic events and are precautionary as for the Italian Standards in force (/1/). The values of the dynamic amplification factors and characteristic oscillation periods relative to a damping ratio ξ=5% are indicated in Table 2.4 for the horizontal main (H_{max}), horizontal secondary (H_{min}) and vertical (V) motion components.

Table 2.4 Parameters of ground motion for horizontal components H_{max}, H_{min} and vertical components V (damping ratio ξ=5%)

Parameter	H_{max}	H_{min}	V	
F_a	3.00	a. 3.52	b. 2.67	
F_v	2.25	2.90	2.37	
F_d	2.00	2.49	2.32	
T_A (s)	0.03	0.03	0.03	
T_B (s)	0.14	0.08	0.05	$=T_C / 4$
T_C (s)	0.58	0.32	0.19	$=2\pi$ PSV / PSA
T_D (s)	2.33	2.09	2.15	$=2\pi$ PSD / PSV
T_E (s)	9.31	8.38	8.62	$=T_D \times 4$
T_F (s)	37.23	33.51	34.47	$=T_F \times 4$

Figure 2.1 shows the acceleration response spectra for the three components of the seismic motion on reference subsoil. To account for local amplification effects, refer to instructions in § 3. For the spatial representation of the seismic motion refer to instructions in § 4.

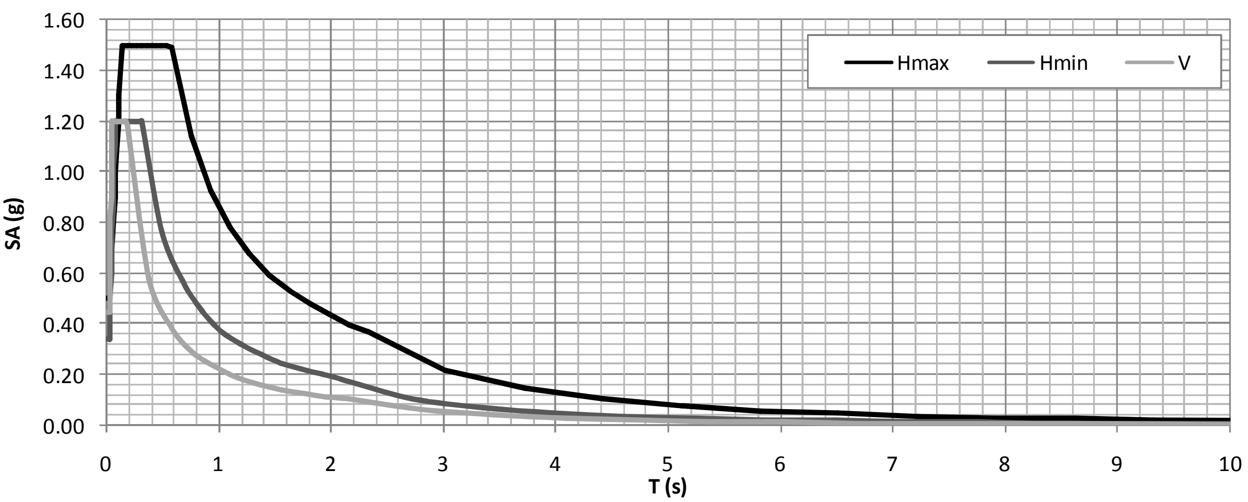

Figure 2.1 Acceleration Response Spectra for H_{max}, H_{min} and V components

For the sake of completeness and in order to allow for further and more detailed structural analysis also the response spectra associated to a value of the damping ratio ξ=2% are given. The values of the dynamic amplification factors and of the characteristic oscillation periods for the main horizontal (H_{max}), horizontal secondary (H_{min}) and vertical (V) motion components are indicated in Table 2.5.

Table 2.5 Parameters of ground motion for horizontal H_{max}, H_{min} and vertical V components (damping ratio ξ=2%)

Parameter	H_{max}	H_{min}	V	
F_a	4.19	4.91	3.72	
F_v	3.05	3.93	3.21	
F_d	2.47	3.07	2.86	
T_A (s)	0.03	0.03	0.03	
T_B (s)	0.14	0.08	0.05	$=T_C / 4$
T_C (s)	0.56	0.31	0.18	$=2\pi$ PSV / PSA
T_D (s)	2.12	1.91	1.96	$=2\pi$ PSD / PSV
T_E (s)	8.47	7.63	7.84	$=T_D \times 4$
T_F (s)	33.90	30.51	31.38	$=T_F \times 4$

2.3 Recorded and Simulated Accelerograms

The ground shaking can be represented in terms of acceleration time histories and relevant quantities representing the ground displacement (velocity and displacement). The seismic movement is described in three accelerograms representing the three spatial components of the motion (two horizontal components and a vertical component). To this purpose, artificial accelerograms, recorded or simulated, satisfying the spectro-compatibility criteria of the Italian Standards (/1/) and of the European Standards (/2/) can be used.

For the purposes of the design for Progetto Definitivo of the Messina Bridge and following the studies made in document /5/, four sets of accelerograms are given, of which two are artificial accelerograms generated according to the mentioned spectro-compatibility criteria, and two natural accelerograms, representing some peculiar shaking characteristics that can be noticed in ground motions in areas close to the surface fault rupture. Each set of accelerograms consists of two horizontal components (the main H_{max} and the secondary H_{min} one) and of a vertical component (V).

In essence, the accelerogram sets supplied are:

1. Set of three artificial accelerograms identified as group **A1**;
2. Set of three artificial accelerograms identified as group **A2**;
3. Set of three natural accelerograms, chosen among the recordings previously selected, particularly representative of the near-fault effects: to this purpose, the set of accelerograms recorded in Arcelik station during Kocaeli seismic event of 17.08.1997 (Magnitude M_W=7.51) identified as group **14** is used;
4. Set of three natural accelerograms, with frequency content similar to that of the design spectrum and characterized by a Magnitude and a minimum distance from the fault that can be compared with those foreseen at the site: to this purpose, accelerograms recorded in Darfield High School station during the New Zealand Earthquake of 03.09.2010 (Magnitude M_W=7.00) identified as group **NZ** have been selected.

In addition, accelerograms corresponding to a seismic event certainly exceeding the expected seismic event, recorded in Concepcion San Pedro station during Chile earthquake of 27.02.2010 (Magnitude M_W=8.80) identified as group **CH** are supplied. This latter accelerogram set can be considered corresponding to a limit event, higher than the maximum expected event, to be used to assess the behaviour of the structure for a seismic event exceeding the design earthquake.

The accelerogram sets supplied represent the seismic motion expected in the reference subsoil. To consider the local amplification effects, please refer to the instructions of § 3. For the spatial representation of the seismic motion please refer to the instructions of § 4.

3 Local Amplification Effects

For the purpose of the evaluation of the local amplification effects, in the dynamic analyses the accelerograms shall be used as seismic input to be carried over to the rigid substrate with appropriate deconvolution techniques. In evaluating the structural response, soil-structure interaction effects shall be considered.

4 Spatial Model of the Seismic Action

The spatial representation of the seismic action at a point of the ground is obtained through the use of components that describe the seismic motion in three mutually perpendicular directions: a main component in the horizontal plane (H_{max}), a main component in the horizontal plane (H_{min}) and a component in the vertical plane (V). In the evaluation of the structural response, the main horizontal component shall be applied in different directions, sweeping an angle of 360° in steps not exceeding 15°, and the three components shall correctly rotate around the vertical axis.

5 Bibliography

/1/ Technical Standards for Constructions NTC08, Ministry Decree of 14/1/2008, Suppl. ord. no. 30 to Official Bulletin no. 29 of 4/2/2008.

/2/ Eurocode 8, 1998-1 (2005). Design of structures for earthquake resistance design Part 1: General rules, seismic actions and rules for buildings.

/3/ Eurocode 8, 1998-2 (2005). Design of structures for earthquake resistance design Part 2: Bridges.

/4/ AASHTO, 2009. AASHTO Guide Specifications for LRFD Seismic Bridge Design.

/5/ Professor Braga: Definition of Seismic Actions for the Messina Strait Bridge 12 June 2010