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Rosella Caruana

Seismic Aspects of Dam Design

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SEISMIC ASPECTS OF DAM DESIGN (2020-23)

CHAIRMAN

M. WIELAND
Herostrasse 12
CH-8048 Zurich
SWITZERLAND / SUISSE
Fax : +41 44 3555563
Phone : +41 76 3562862
martin.wieland48@gmail.com

VICE-CHAIRMEN

T. MATUSCHKA
P O Box 301054, Albany
0752 Auckland
NEW ZEALAND / NOUVELLE-ZÉLANDE
Fax :
Phone : 64 9 4862546
trevor.matuschka@enggeo.co.nz

L. MEJIA
72 Camino Sobrante
94563 Orinda
USA / ETATS-UNIS
Fax :
Phone :
LMejia@geosyntec.com

MEMBER

K. ADDO
6911 Southpoint Drive
V3N 4X8 Burnaby
CANADA / CANADA
Fax :
Phone : 1.604.528.7725
kofi.addo@bchydro.com

A. AZLAN
School of Civil Engineering, Universiti Teknologi Malaysia
81300 Johor Bahru
MALAYSIA / MALAISIE
Fax :
Phone : 019-7551665
mycold.seismic@gmail.com

F. BLAZQUEZ PRIETO
Canal de Isabel IIDivision Control y EstructurasSanta Engracia, 12528003
MADRIDESPAGNE
SPAIN / ESPAGNE
Fax : (34-91) 54 14 27
Phone : (34-91) 545 11 58
fblazquez@cyii.es

A. BUGAEVSKY
RUSSIE
RUSSIA / RUSSIE (FÉDÉRATION DE)
Fax :
Phone :
a.bugaevsky@gmail.com

J. CAMPAÑA
Antonio Varas 621
7500966 Santiago
CHILE / CHILI
Fax :
Phone : +56 9 92992260
jose.campana@arcadis.com

J. CARMONA
L.G. San Martin (Oeste) 12905400 SAN JUANProvincia de San JuanARGENTINE
ARGENTINA / ARGENTINE
Fax :
Phone : (54-264) 423 0147
jcarmona@interredes.com.ar

R. CARUANA (MS)
ITALY / ITALIE
Fax :
Phone : (32-06) 8305 3567
rosella.caruana@enel.com

M. DAVOODI
Arghavan st., North Dibajle, Farmanieh
1953714453 Tehran
IRAN / IRAN (RÉP. ISLAMIQUE D')
Fax : 00982122833865
Phone : 00982122806600
m-davood@iiees.ac.ir

T. HARNPATTANAPANICH
125 the Phann building 3rd floor, khlong lam Chiak Road, nawamin Bueng Kum
10230 Bangkok
THAILAND / THAILANDE
Fax :
Phone : 660818692573
thanuharn@gmail.com

K. HOEG
P.O.Box 3930 Ullevaal Stadion
NO-0806 OSLO
NORWAY / NORVEGE
Fax : + 47 2223 0448
Phone : + 47 9286 7556
kh@ngi.no

B. KENDARAGAMA
Queen
3004 Melbourne
AUSTRALIA / AUSTRALIE
Fax : +61395141502
Phone : +61403204066
Bandula.Kendaragama@gmail.com

D. KIM
KOREA (REP.OF) / COREE (REP. DE)
Fax :
Phone :
dskim@kaist.ac.kr

I. LANDON-JONES
6 Bendtree Way
2154 Castle Hill
AUSTRALIA / AUSTRALIE
Fax : 61 2 4725 3215
Phone : 61419225704
ilandonjones@gmail.com

C. MARULANDA
C/o IngetecCarrera 6, NA°30-30BOGOTACOLOMBIE
COLOMBIA / COLOMBIE
Fax :
Phone :
marulanda@ingetec.com.co

M. PETKOV
Lybotran
1407 Sofia
BULGARIA / BULGARIE
Fax :
Phone : +359883312967
marto@gbg.bg

L. PETKOVSKI
Partizanski Odredi 24
1000 Skopje
NORTH MACEDONIA / MACÉDOINE DU NORD
Fax :
Phone : 389 71 258 465
petkovski@gf.ukim.edu.mk

A. RASHED
5 Ibn Marawan Street Dokki
12311 Giza
EGYPT / EGYPTE
Fax : 0020237607239
Phone : 0020237607238
a.rashed@hamza.org

Z. RAZA
Main street
22850 Ghazi
PAKISTAN / PAKISTAN
Fax :
Phone : 0092995350006
zahidrazageo@yahoo.com

M. ROMO
Geotechnical DepartmentInstitute of EngineeringNational University of MexicoCoyoacan 04510MEXICO, DFMEXIQUE
MEXICO / MEXIQUE
Fax : (52-56) 16 07 84
Phone : (52-56) 22 35 00
mromo@pumas.iingen.unam.mx

T. SASAKI
JAPAN / JAPON
Fax :
Phone :
sasaki-t92ta@nilim.go.jp

P. SECO E PINTO
Av. do Brasil, 1011700 LISBOAPORTUGAL
PORTUGAL / PORTUGAL
Fax : (351-21) 849 76 60
Phone : (351-21) 848 21 31
pspinto@lnec.pt

L. SPASIC-GRIL
42 Mannock Way
RG5 4XW Reading
UNITED KINGDOM / ROYAUME-UNI
Fax : (44-20)7755 2121
Phone : (44-20) 7636 1531
ljiljana.spasic-Gril@arup.com

K. TERHEIDEN
Pfaffenwaldring
70569 Stuttgart
GERMANY / ALLEMAGNE
Fax :
Phone : 004971168564750
kt@iws.uni-stuttgart.de

R. VISHNOI
4/10, THDC Colony
249201 Rishikesh
INDIA / INDE
Fax :
Phone : +919719653930
rkvishnoi2001@yahoo.com

H. WANG
IWHR Earthquake Research Center, No.20 West Chegongzhuang Road
100048 Bijing
CHINA / CHINE
Fax :
Phone : +8613910779970
wanghb@iwhr.com

G. ZENZ
Stremayrgasse 10/II
8010 Graz
AUSTRIA / AUTRICHE
Fax :
Phone : 00433168738360
gerald.zenz@tugraz.at

CO-OPTED MEMBER

E. SANTOS
Guillermo Acuña 2827
7510960 Santiago
CHILE / CHILI
Fax :
Phone : +56988066649
eloy.santos.osandon@gmail.com

Seismic Aspects of Dam Design

Bollettini pubblicati:

Bulletin 52 (1986): Earthquake analysis procedures for dams, ANALYSIS

Bulletin 112 (1998): Neotectonics and dams HAZARD

Bulletin 113 (1999): Seismic observation of dams INSPECTION

Bulletin 120 (2001): Design features of dams to resist seismic ground motion DESIGN

Bulletin 123 (2002): Earthquake design and evaluation of structures appurtenant to dams DESIGN

Bulletin 137 (2011): Reservoirs and seismicity HAZARD

Bulletin 148 (2016): Selecting seismic parameters for large dams DESIGN (Linee guida revisione del n.72)

Bulletin 166 (2016): Inspection of dams following earthquakes INSPECTION (Linee guida revisione del n. 62)

Seismic Aspects of Dam Design

Bollettino 148 sommario

CHOIX DES PARAMÈTRES SISMIQUES POUR GRANDS BARRAGES
Recommandations

SELECTING SEISMIC PARAMETERS FOR LARGE DAMS
Guidelines

Bulletin 148

CIGB ICOLD

2016

Cover/*Couverture* :
Cover illustration: Severe cracking along crest of earth dam, caused by the magnitude 7.7 Bhuj earthquake of January 26, 2001 (Gujarat, India) (Photo S. K. Jain)/ *Illustration en couverture : Fissuration grave le long de la crête du barrage en terre, provoquée par le tremblement de terre de Bhuj, de magnitude de 7,7 du 26 janvier 2001*

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4. CHOIX DES PARAMÈTRES SISMIQUES DE CALCUL	4. SELECTION OF SEISMIC EVALUATION PARAMETERS
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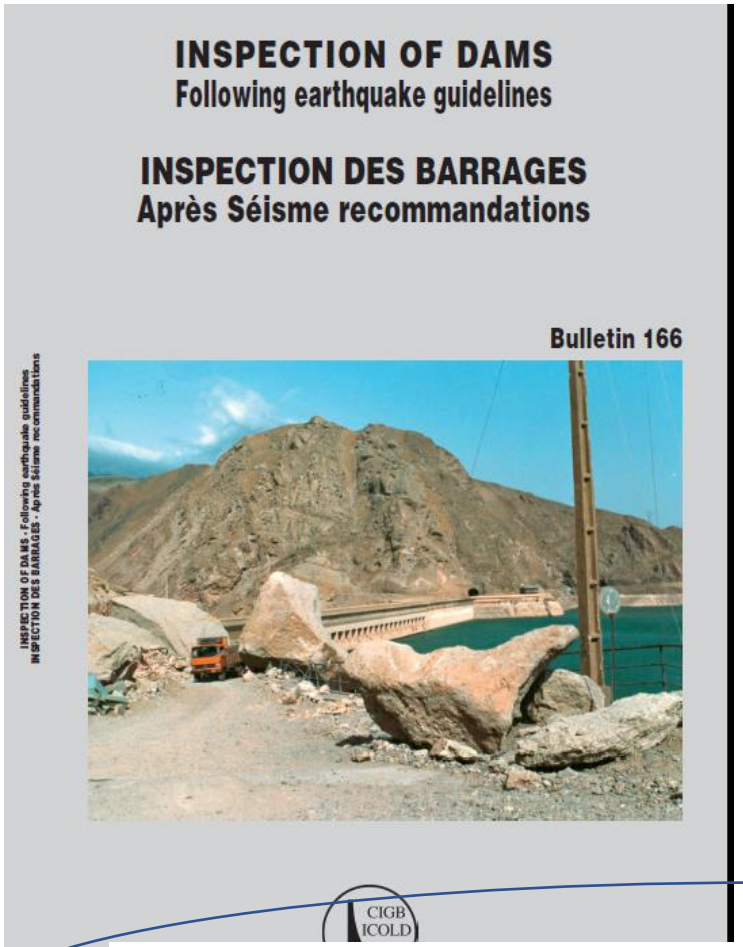
Seismic Aspects of Dam Design

Bollettino 166 sommario



Cover/Couverture :

Cover illustration: Rockfall at the left abutment above the morning glory spillway of the 105 m high Sefid Rud buttress dam, caused by the magnitude 7.4 Manjil earthquake of June 20, 1990 (Alborz

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4. INSPECTION SUPPLÉMENTAIRE	4. FOLLOWUP ENGINEERING INSPECTION
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Seismic Aspects of Dam Design

Terms of References 2020 -2023

- **Effetti prodotti sulle dighe da terremoti importanti**
- **Consolidamento delle conoscenze in merito a :**
  - **Sicurezza sismica di dighe esistenti**
  - **Criteri di progetto**
- **Diffusione delle conoscenze**
- **Approfondimento del comportamento sismico di dighe in materiali sciolti**
- **Sicurezza sismica**

Bollettino in corso

Seismic Aspects of Dam Design

ICOLD POSITION PAPER ON DAM SAFETY AND EARTHQUAKES

Sicurezza sismica di una diga:

- Analisi di pericolosità sismica
- Modellazione dei sistemi diga serbatoio fondazione
- Modelli dei materiali e delle proprietà dinamiche
- Definizione dei criteri di prestazione sismica

Comportamento sismico delle dighe in occasioni di forti terremoti

→ **raccogliere analizzare interpretare le osservazioni**

Seismic Aspects of Dam Design

- **Le attenzioni principali per le dighe esistenti (Bollettino 120 Caratteristiche progettuali delle dighe ai fini della resistenza alle scosse sismiche Linee guida e casistica)**
- **L'attività continua del TC ha evidenziato l'importanza fondamentale di raccogliere le osservazioni durante i terremoti**
- **Strumentazione sismica delle dighe**

Compito principale del Comitato Tecnico è la diffusione delle conoscenze in merito al comportamento sismico delle dighe

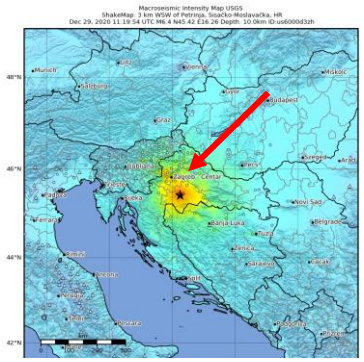
- **Gruppo di lavoro ITCOLD sul comportamento delle dighe italiane in occasione di terremoti importanti → *Bollettino 2018***

- **Osservatorio specifico ITCOLD che in collaborazione con il TC raccoglie e diffonde le osservazioni degli effetti di terremoti**

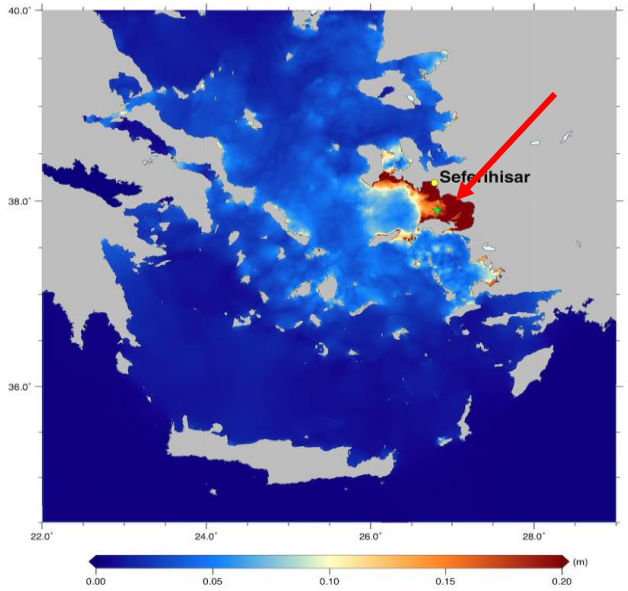
Seismic Aspects of Dam Design

ITCOLD - Osservatorio Dighe - Sismi

Croatia 29 Dicembre 2020 Terremoto di magnitudo M6.4
Profondità 10 Km;



Samos (Grecia) 30 Ottobre 2020 Terremoto M 7.0 profondità di 16.5 km, epicentro 19 km a nord dell'isola di Samos (Grecia) e 17.26 km a Sud della costa della Turchia nella parte orientale del mar Egeo.



South California :

4 e 6 luglio 2019 due scosse di terremoto di M 6.4 e M 7.1

Seismic Aspects of Dam Design

TERREMOTI RECENTI IMPORTANTI CHE HANNO INTERESSATO UN BUON NUMERO DI DIGHE

Maggio 2008 **Wenchuan earthquake** China
1800 dams, and **400 hydropower plants** 4 dighe con altezza > 100 m

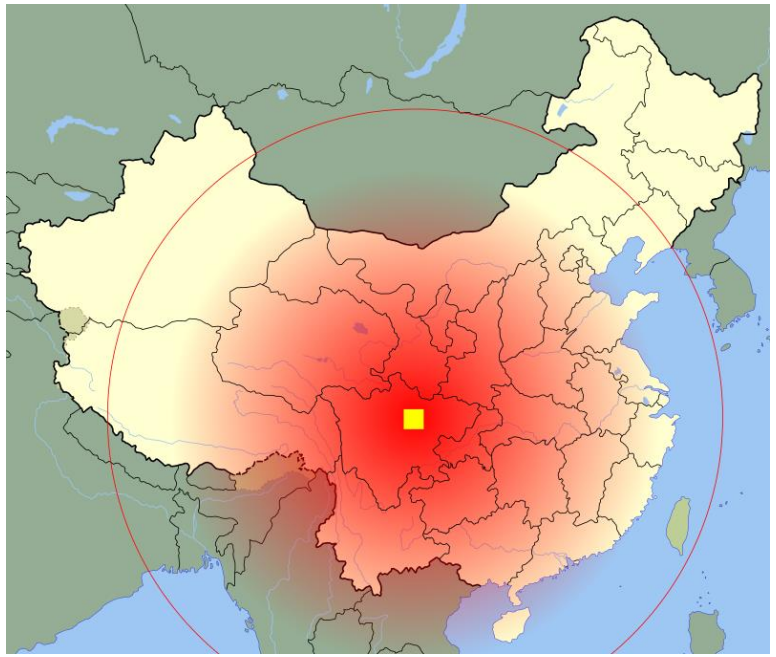
January 2001 **Bhuj earthquake** India
245 dams – mainly small embankment dams – Hanno avuto bisogno di interventi

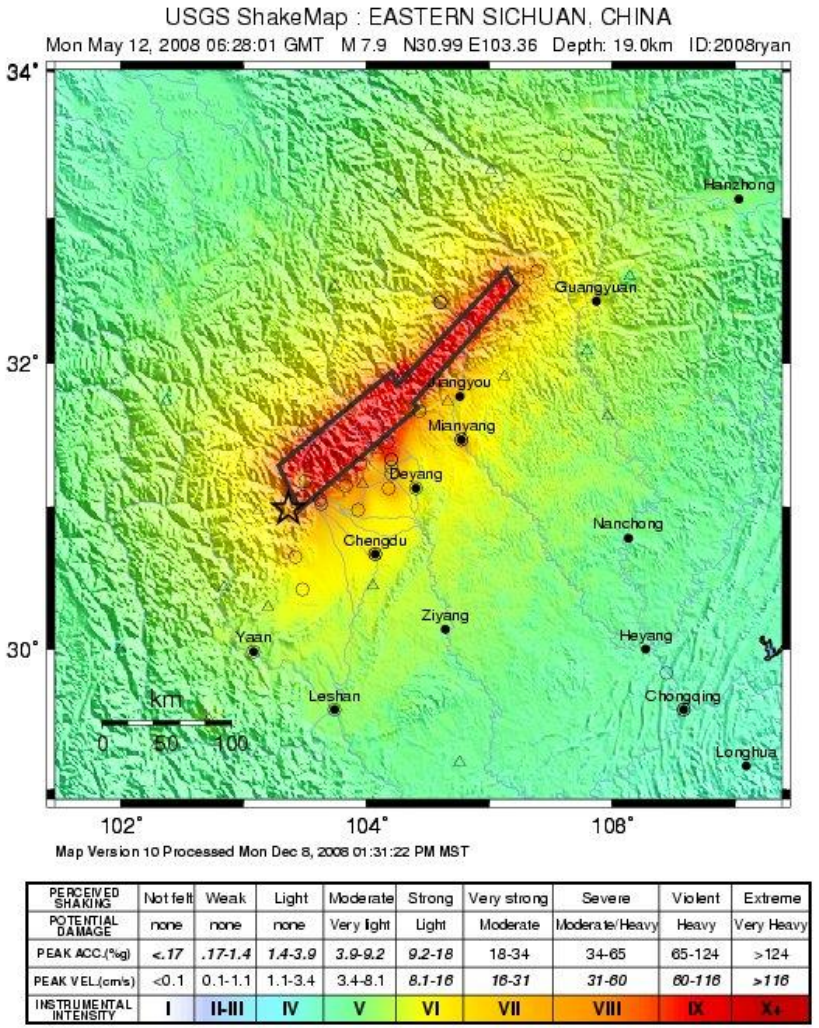
June 2008 **Iwate-Miyagi Nairiku earthquake** Japan **134 dams** had to be inspected

Segue una serie di foto relative ad effetti rilevati dopo terremoti importanti su dighe di diverse tipologie

Seismic Aspects of Dam Design

Terremoto WENCHUAN 12 Maggio 2008





PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<.17*	*.17-1.4*	*1.4-3.9*	*3.9-9.2*	*9.2-18*	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	*8.1-16*	*16-31*	*31-60*	*60-116*	*>116*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

12 Maggio 2008
Magnitudo M 7.9

Localita' più prossime all'epicentro: Guangkou (34 Km), Chengdu (94 Km, citta' di 4 milioni di abitanti)

Seismic Aspects of Dam Design

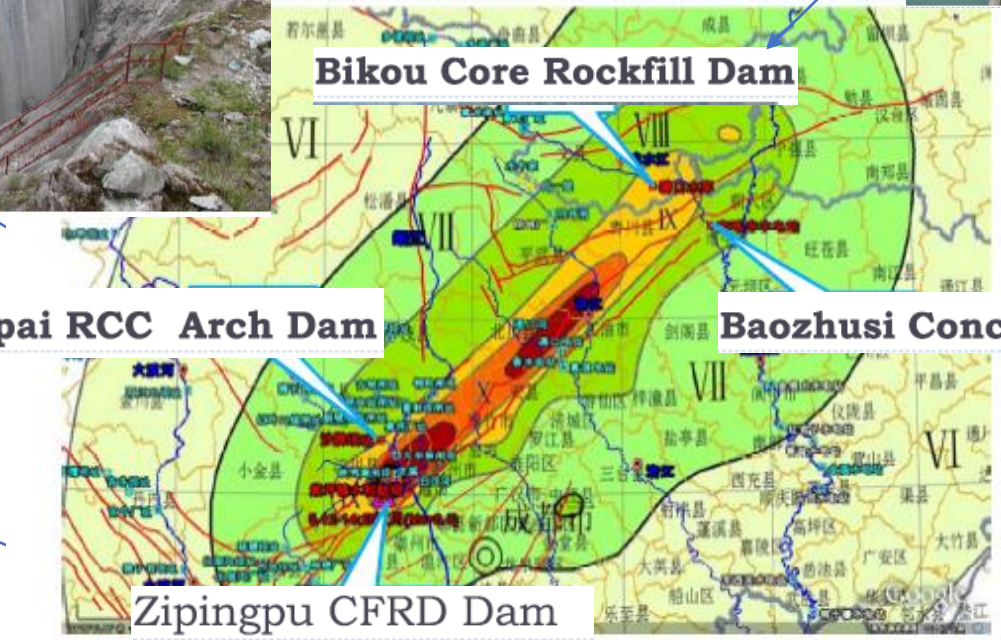
2008 Wenchuan Earthquake

- Local Time: 14:28:04, May 12, 2008
- Magnitude: 8.0Ms
- Depth: 10~20Km
- Fault length: more than 200km
- Epicenter: Wenchuan County, Sichuan Province, China
- Dead or missing: more than 90,000
- Injured: 374,643
- Economic loss: higher than US$100 billion

Performance of Dams

- More than 1,800 dams exposed to strong earthquake shaking.
- 69 dams were judged in the highest risk
- 310 dams were judged in high risk
- 1424 dams were reported with minor damages
- No dam collapses due to the Wenchuan Earthquake
- 4 dams more 100m in height was severely shaken but all damages are at repairable level.

ore 100m in height



Seismic Aspects of Dam Design

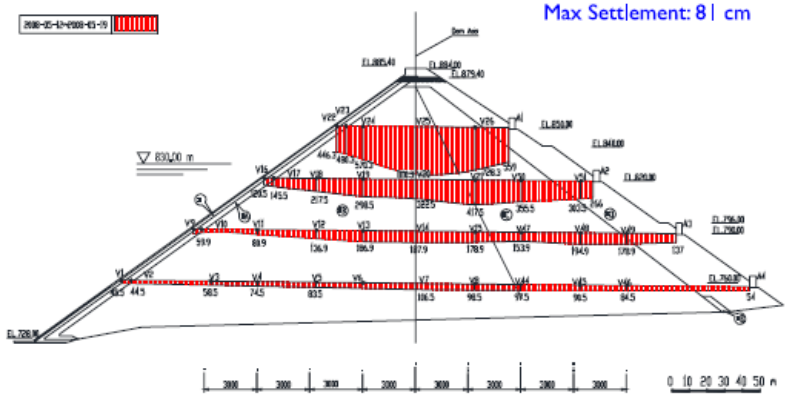
ZIPINGPU Concrete-Face Rockfill Dam 158 m 17km dall'epicentro

Performance of Zipingpu CFRD Dam

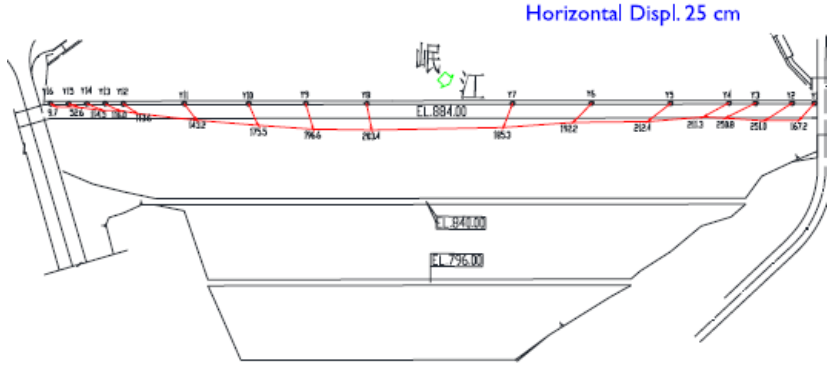
Performance of Zipingpu CFRD Dam

- Completed in May 2006
- 158 m in height
- 663 m in crest length
- Normal water level is EL. 877m
- Storage capacity of 1.12 billion cubic meters
- 760 MW installed capacity
- Design PGA is 0.260g
- 17 km from the epicenter of Wenchuan Earthquake
- Water level was 46 meters below the normal
- 0.33 billion cubic meters water in the reservoir

Performance of Zipingpu CFRD Dam



Performance of Zipingpu CFRD Dam



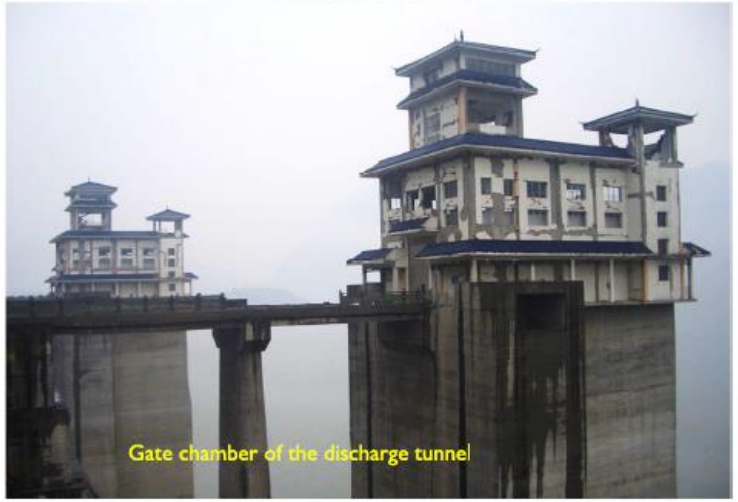
Seismic Aspects of Dam Design

12 maggio 2008 Terremoto di Wenchuan M 7.9;

Zipingpu Concrete Face Rockfill Dam (156 m)

Seismic Aspects of Dam Design

Performance of Zipingpu CFRD Dam



Performance of Zipingpu CFRD Dam

Performance of Zipingpu CFRD Dam

- ✓ Dopo il terremoto di WENCHUAN in Cina è stata rivista la normativa sismica in particolare per le dighe in classe 1

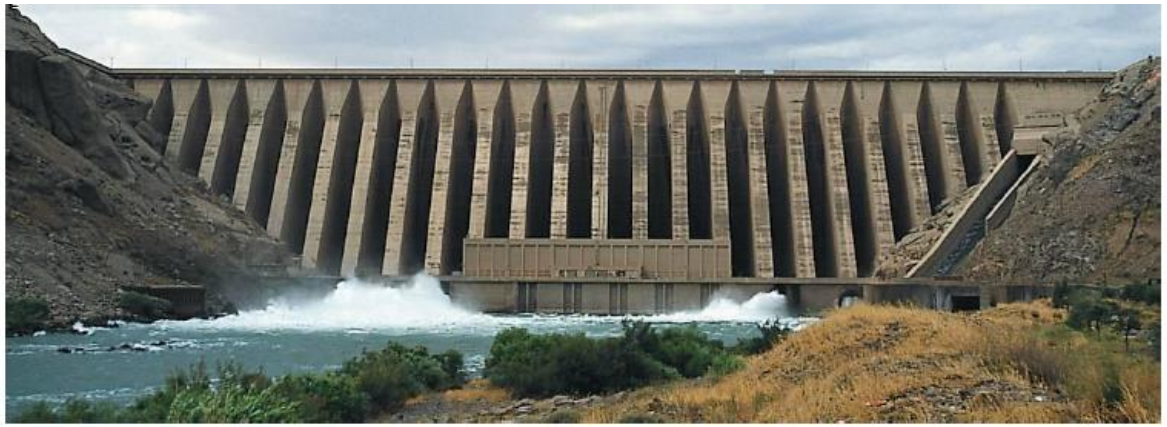
- ✓ Diverse dighe ad arco realizzate dopo Wenchuan :

Xiaowan (294.5m), Xiluodu(285,5m) Dagangshan (210m)
sono state dotate di irrigidimenti per ridurre le aperture di fessure
smorzatori per contrastare le aperture dei giunti

Implications on Dam Design

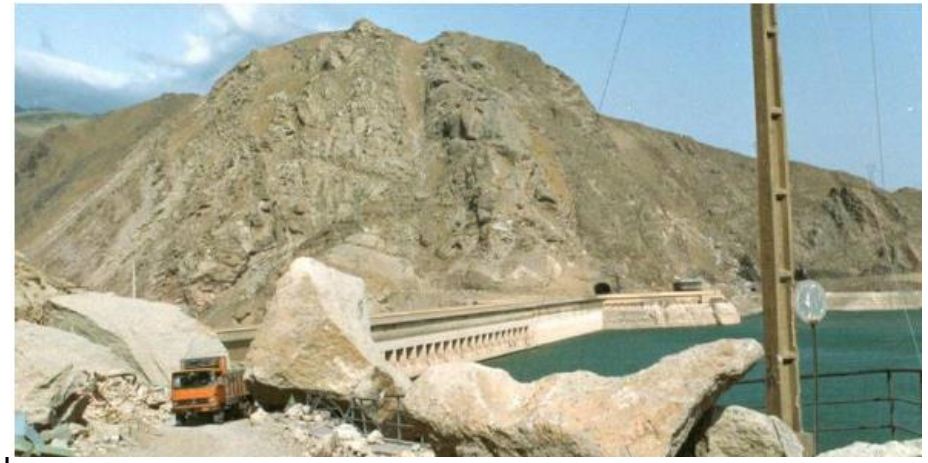
Seismic Aspects of Dam Design

Manjil Earthquake of June 21, 1990 M=7.5
Diga di Sefid Rud Buttress IRAN H 106 m Costruita nel 1962
PGA al sito diga 0,7g



hoto 2: Downstream view of the 106 m high Sefid Rud buttress dam in Iran damaged by the agnitude 7.5 Manjil earthquake of June 21, 1990. Bottom irrigation outlets were opened after the arthquake to lower the reservoir (top). Rockfall damage near left abutment (left bottom) and right outment (bottom right).

Rockfall, Manjil Earthquake 1990, Sefid Rud Dam



Seismic cracks in Sefid Rud Buttress Dam

Critical crack in buttress of Sefid Rud Dam

Seismic Aspects of Dam Design

Bhuj earthquake 26 gennaio 2001 Stato indiano Gujarat, al confine con il Pakistan. M 7.5

Bhuj earthquake 2001

Bhuj earthquake 2001

Bhuj earthquake 2001

Danni riscontrati su dighe in materiali sciolti

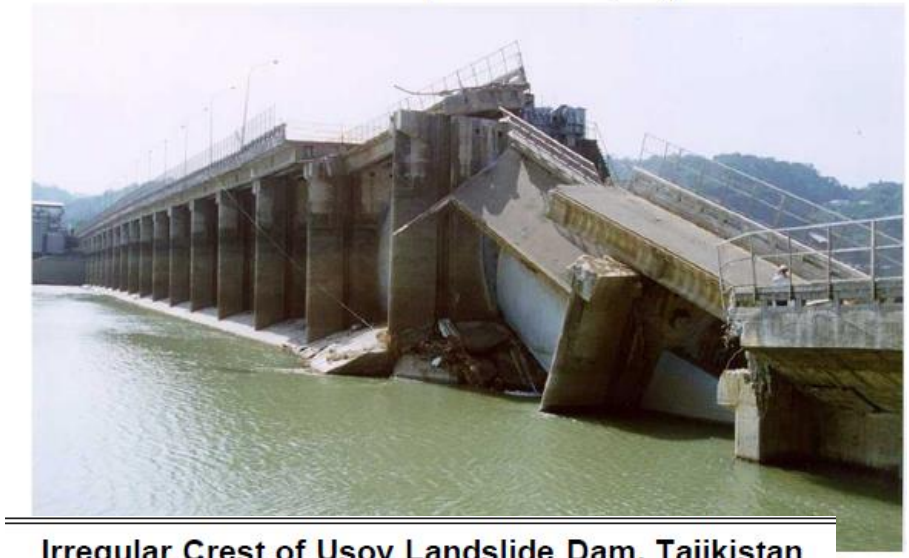
Prevalentemente dighe minori per irrigazione e uso potabile

Seismic Aspects of Dam Design

Manjil earthquake 1990, Sefid Rud dam
Crack in foundation gallery, damaged grout curtain

Faults in dam foundation

Fault Movement, Shih-Kang Dam/Weir, Taiwan
Chi-Chi Earthquake 1999, M_w=7.7



Usoy Landslide Dam (Lake Sarez) Tajikistan
Height: ca. 650 m, Landslide triggered by 1911 M=7.3 earthquake

Landslide

Irregular Crest of Usoy Landslide Dam, Tajikistan

Seismic Aspects of Dam Design

Fujinuma embankment dam 18.5 m
Terremoto Tohoku M=9 Giappone 11 Marzo 2011

Liquefaction of Lower San Fernando Dam, San Fernando Earthquake 1971

Damaged Earth Dam
Bhuj Earthquake 2001, India, Mw=7.7,

Liquefaction of Lower San Fernando Dam, USA
Hydraulic Fill Dam, San Fernando Earthquake 1971, M_w=6.6

Upstream Slide in Kitayama Dam,
Kobe (Great Hanshin) Earthquake 1995, Japan, M_w=6.9

Comportamento sismico dighe in materiali sciolti

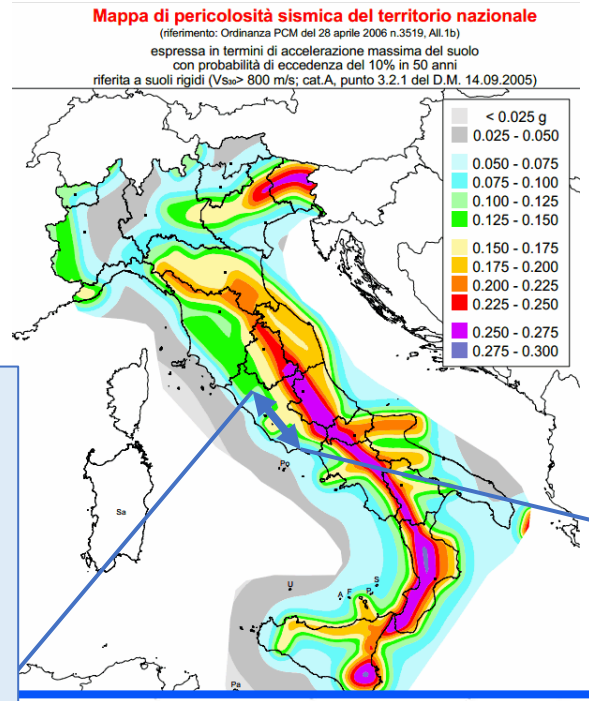
Seismic Aspects of Dam Design

Contributo Italia

- **Terremoto 2009 in Abruzzo**
- **Gruppo di lavoro sul comportamento sismico delle dighe italiane**
- **Terremoto in Italia Centrale 2016 2017**

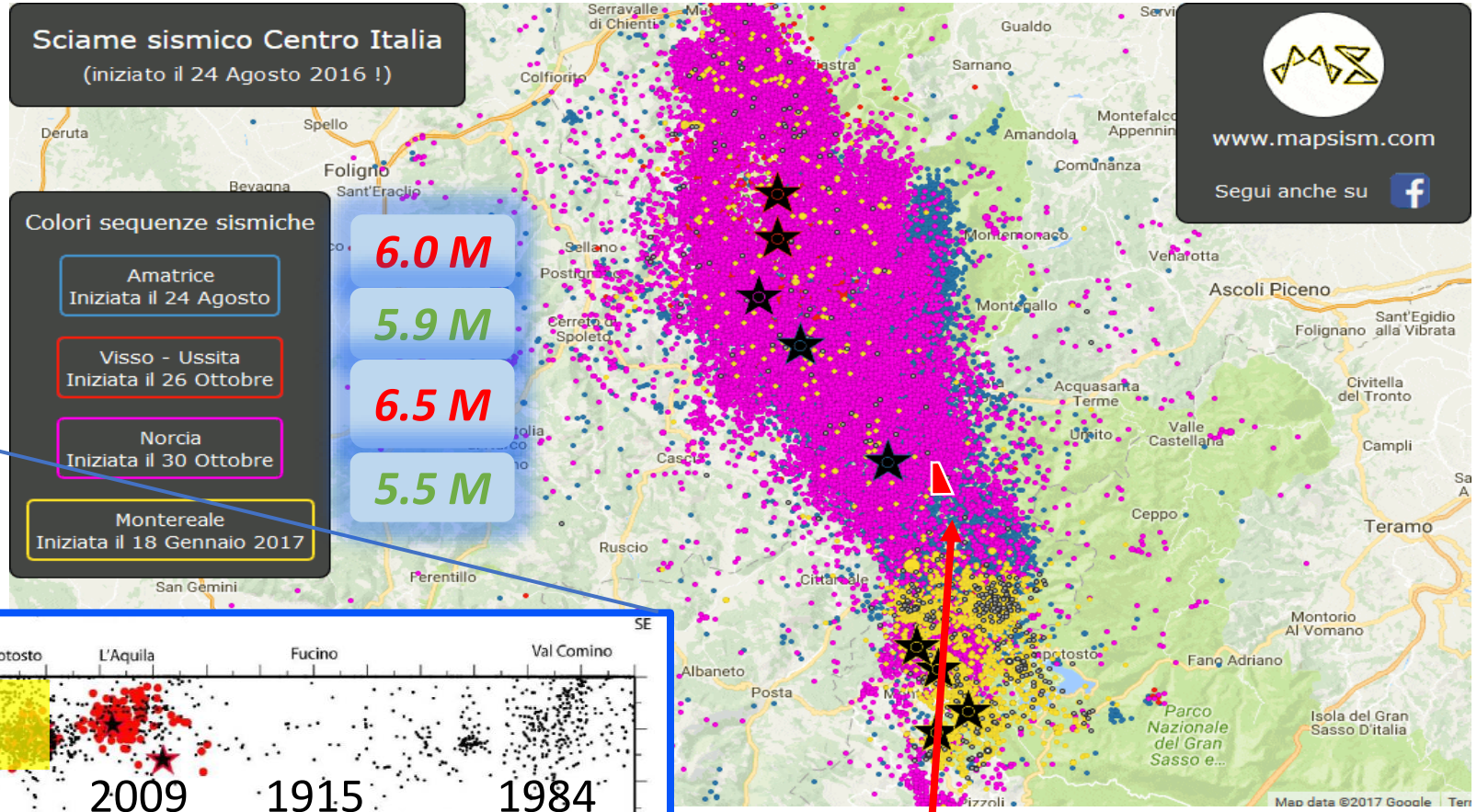
✓ **Risposta della diga di Scandarello**

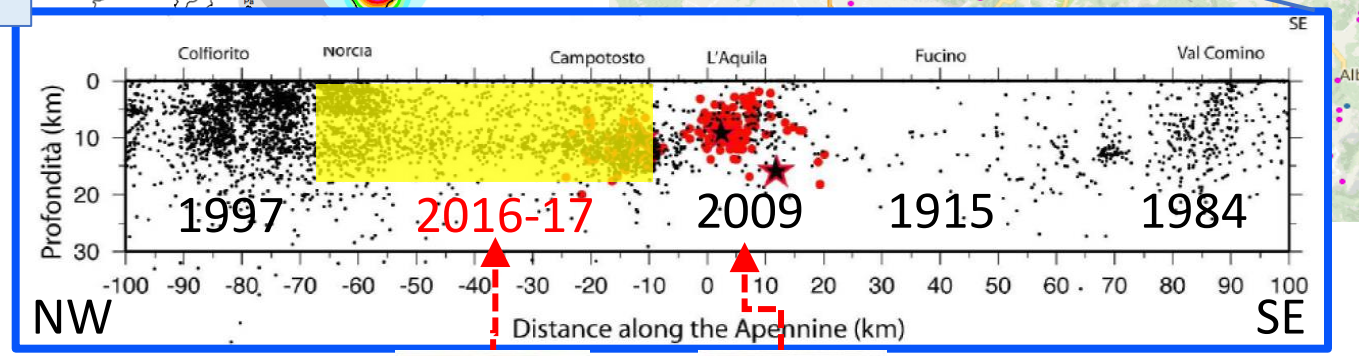
2 Seismic Aspects of Dam Design



Sequenza 2016 - 2017

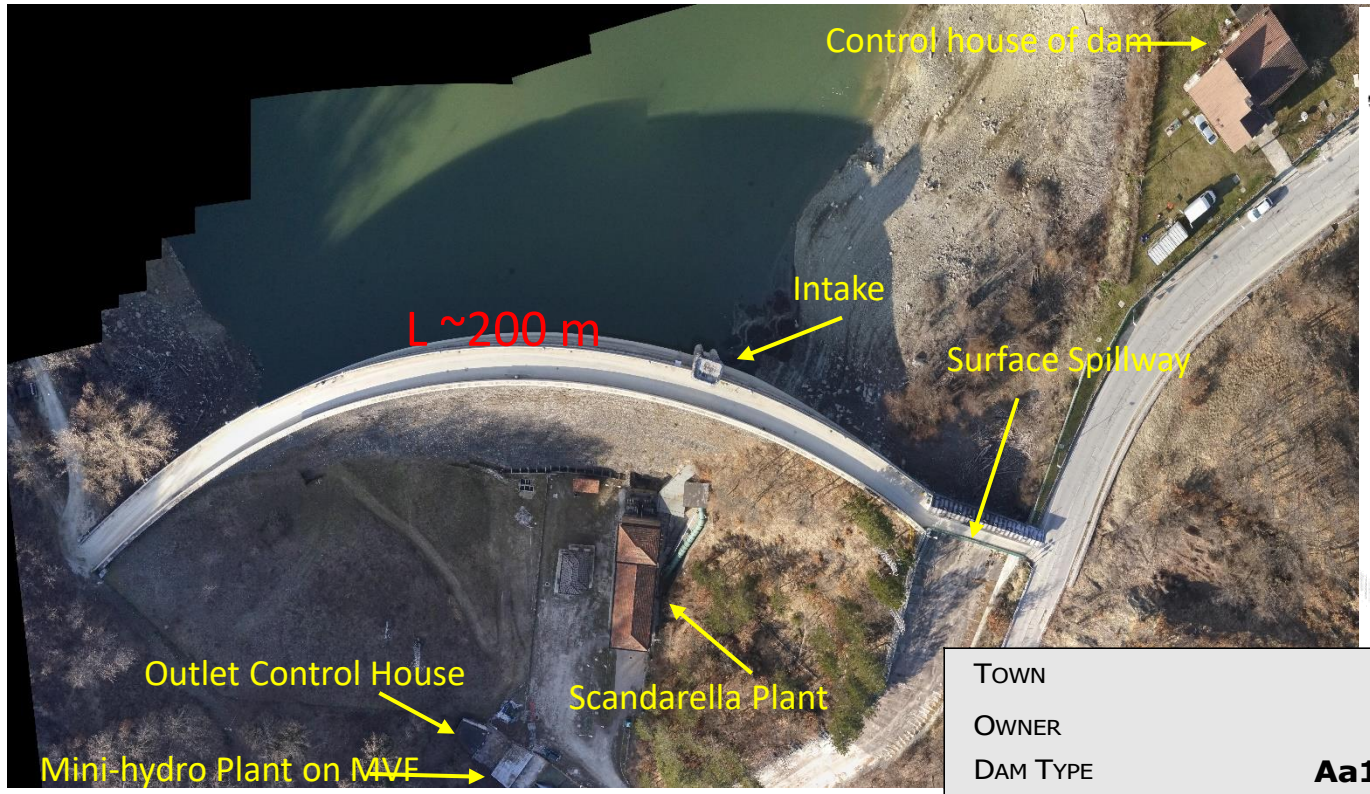
Diga Scandarello

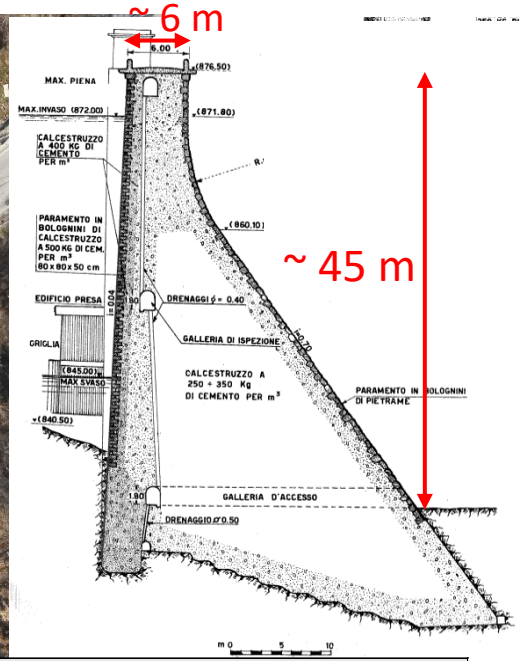




SCANDARELLO DAM

Seismic Aspects of Dam Design





TOWN	**AMATRICE**
OWNER	**ENEL PRODUZIONE**
DAM TYPE	**Aa1 – Gravità, di forma arcuata**
DAM HEIGHT (AI SENSI DELLA LEGGE 584/94)	**45.15 m**
RESERVOIR CAPACITY	**12.500.000 m³**
MAXIMUM WATER LEVEL	**868.30 m s.l.m.**
NORMAL WATER LEVEL	**868.30 m s.l.m.**
MINIMUM WATER LEVEL	**845.30 m s.l.m.**
SEISMICITY CLASSIFICATION	**ZONA 1. PGA (475) = 0.26 g**
YEAR OF COMPLETION	**1927**

DIGA DI SCANDARELLO (***Amatrice (Rieti)***)
Diga a gravità in calcestruzzo senza giunti verticali. Substrato di fondazione in arenaria e marne in una successione di strati misti.

Seismic Aspects

Piccole evidenze di danneggiamento a strutture accessorie

Nessun effetto di rilievo sul corpo diga

Nessuna anomalia rilevante del comportamento della diga

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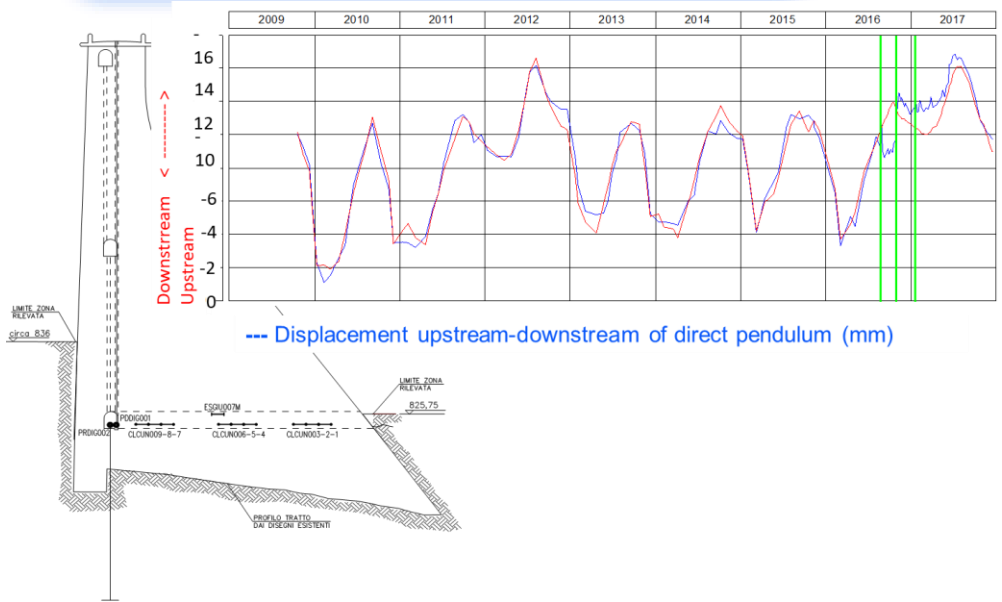
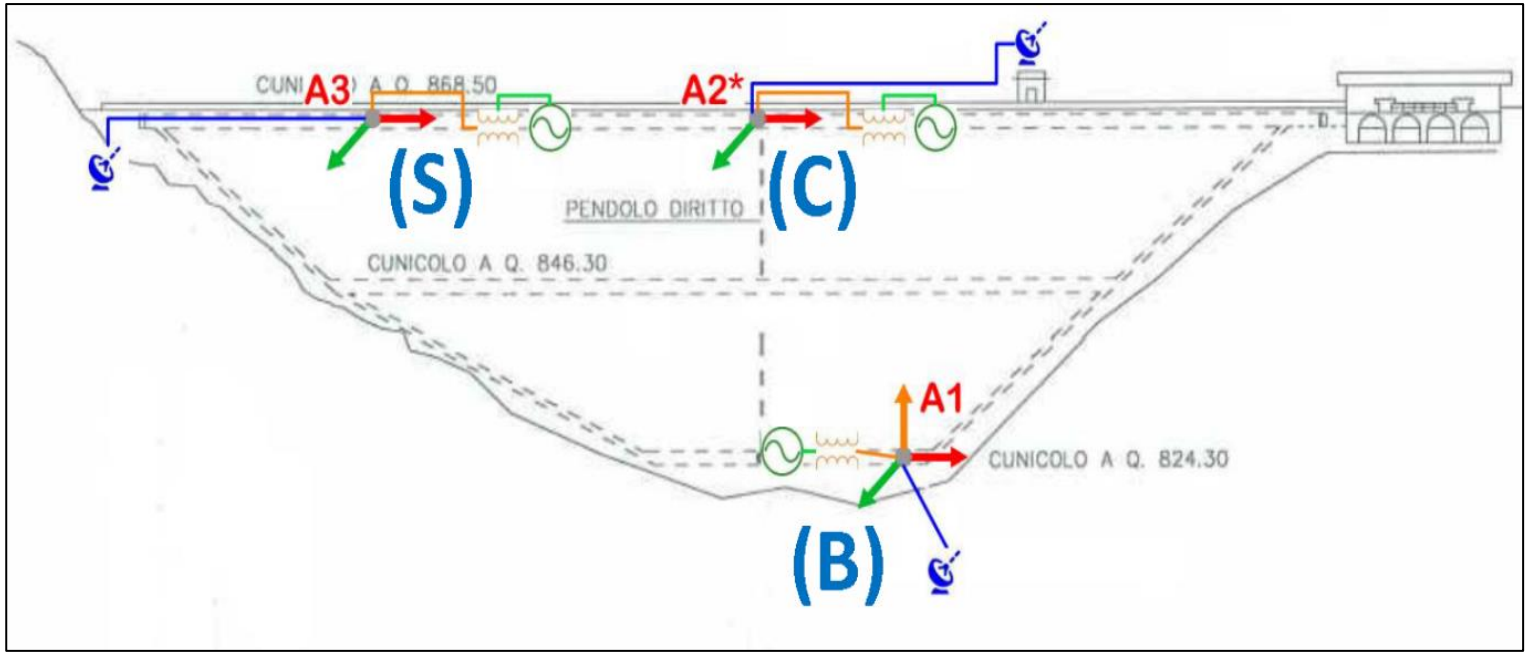


Seismic Aspects of Dam Design

Sistema di monitoraggio sismico installato nel 2017



n. 3 accelerometri (3-axial)
Installati nel 2017 in collaborazione con la Protezione Civile

Seismic Aspects of Dam Design