Professor Chopra´s contributions to

The Panama Canal

and the

Panamanian Structural Design Code

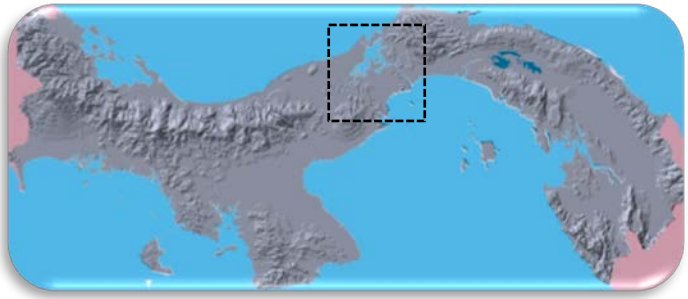
Retirement Symposium
Celebrating the Career of

Anil K. Chopra

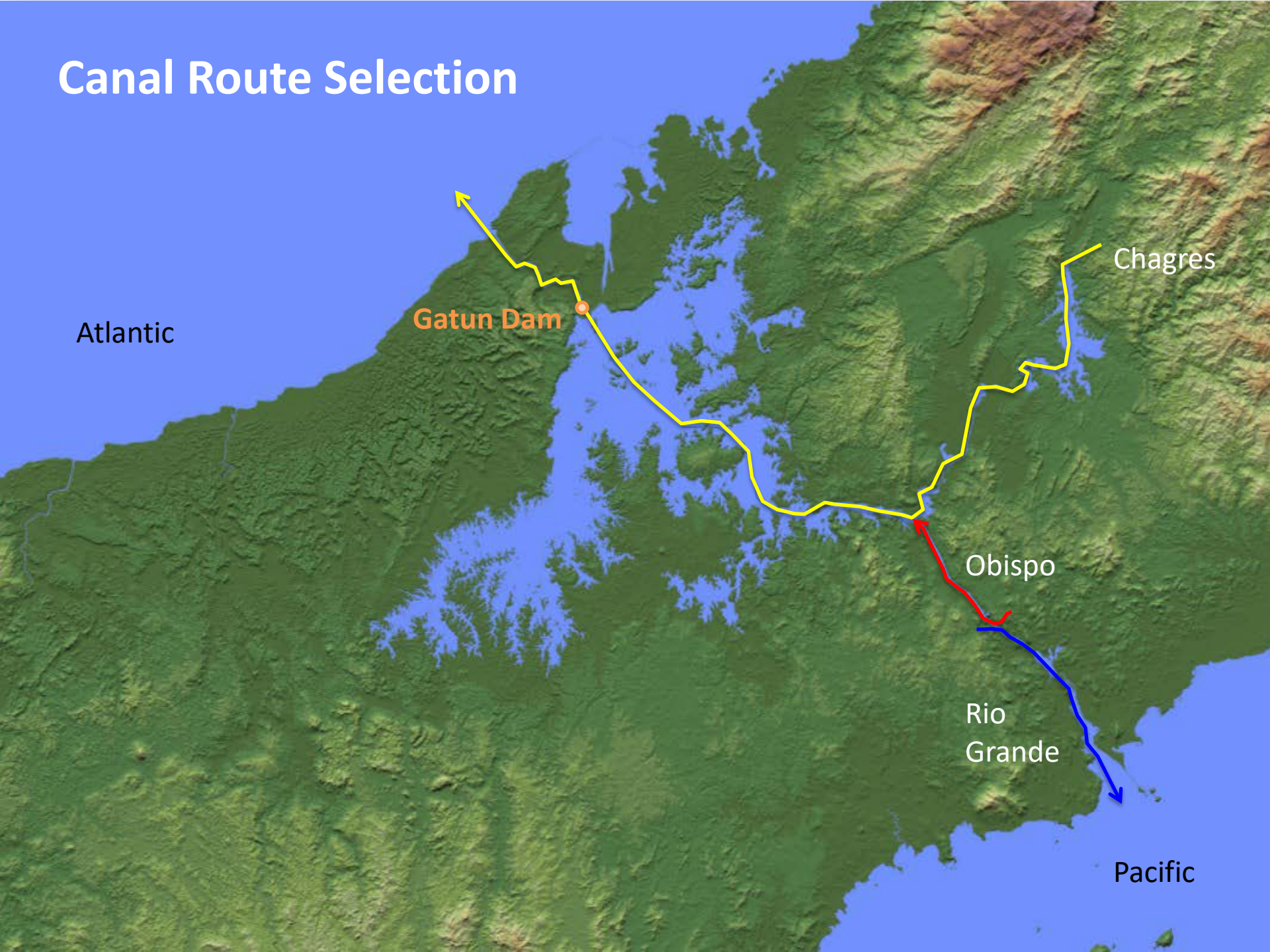
Horace, Dorothy and Katherine Johnson
Professor of Engineering Emeritus
Oct. 2-3, 2017
University of California, Berkeley campus

Luis Alfaro, *Panama Canal Authority (Ret.)*
Fernando Guerra, *Panama Canal Authority*

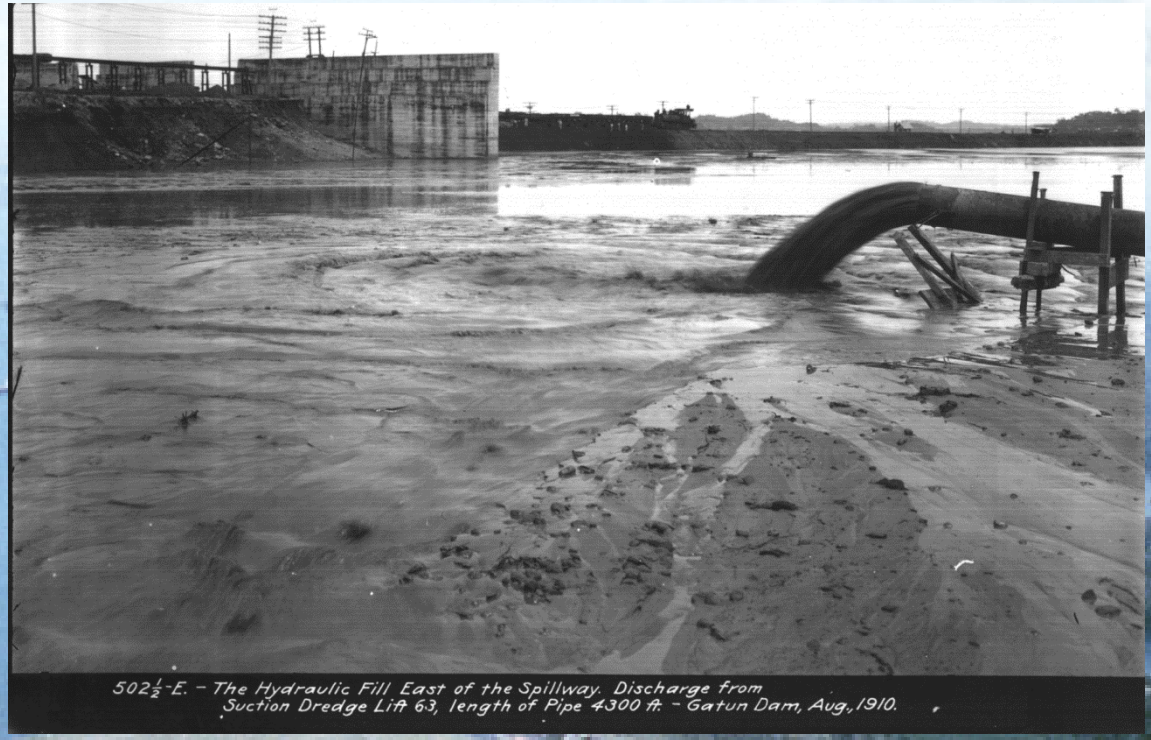
Panamá



Canal Route Selection



Gatun Dam



Crest elevation	32 m PLD
Min. Freeboard	5.0 m
Length	2,500 m
Base width	700 m
Volume	18 M m^3 (≅50% hydraulic fill)

Canal Components

Atlantic Complex

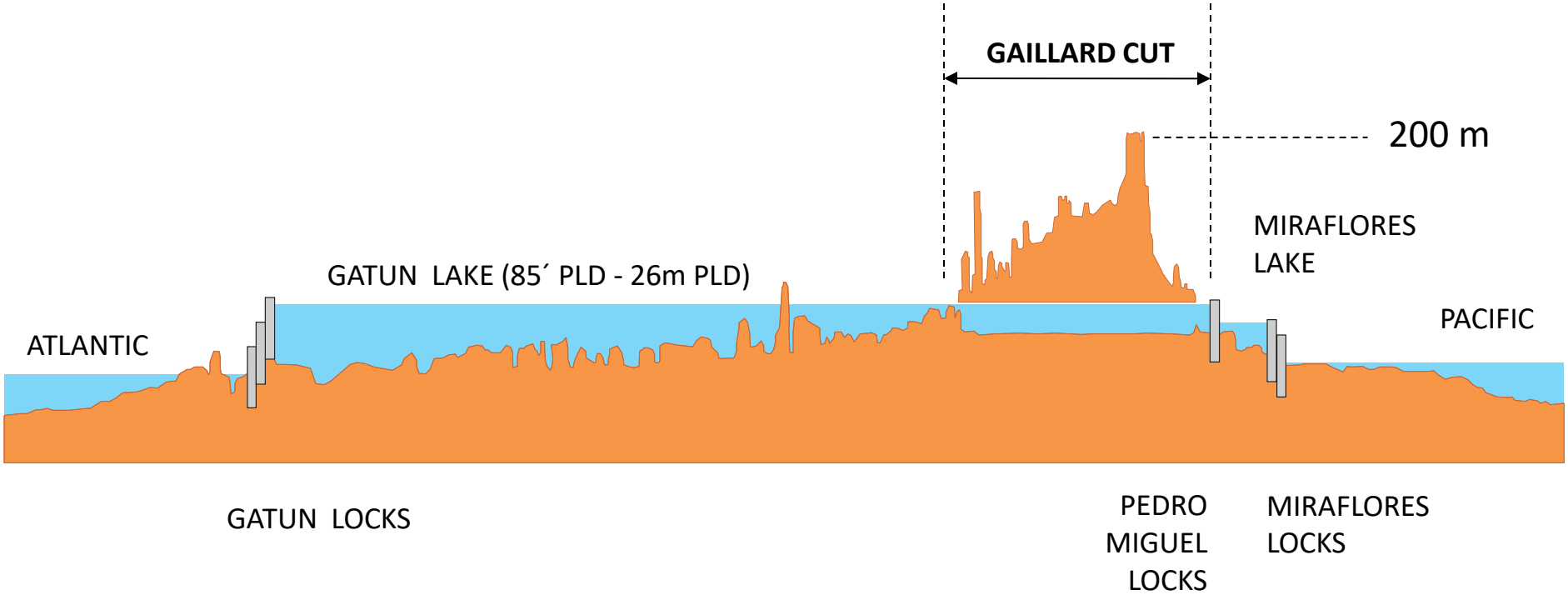
Madden Dam

Gaillard Cut

Pacific Complex

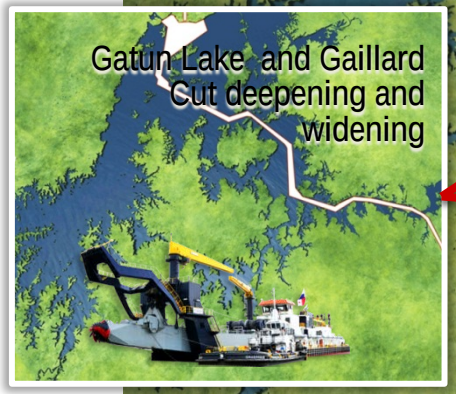
Pacific

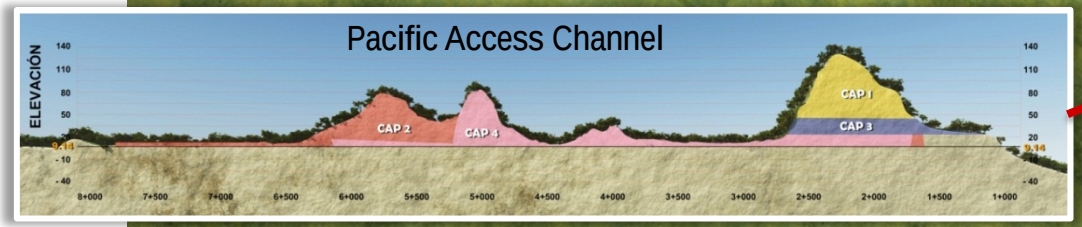
Longitudinal Profile of the Canal



Expansion Program Components (2009-2016)

$5.25 b

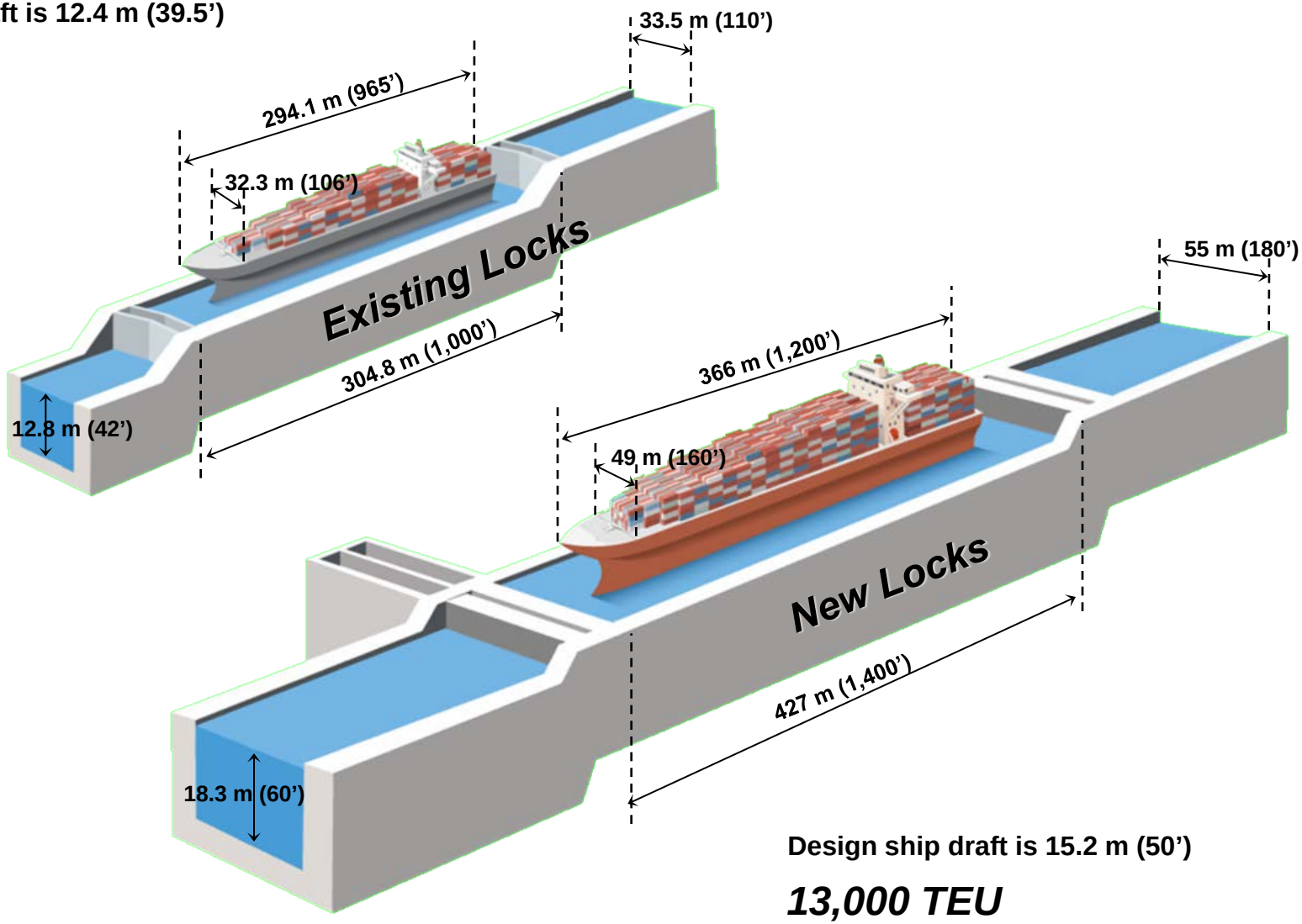




Dimensions of Locks and Ships

Design ship draft is 12.4 m (39.5’)

4,400 TEU

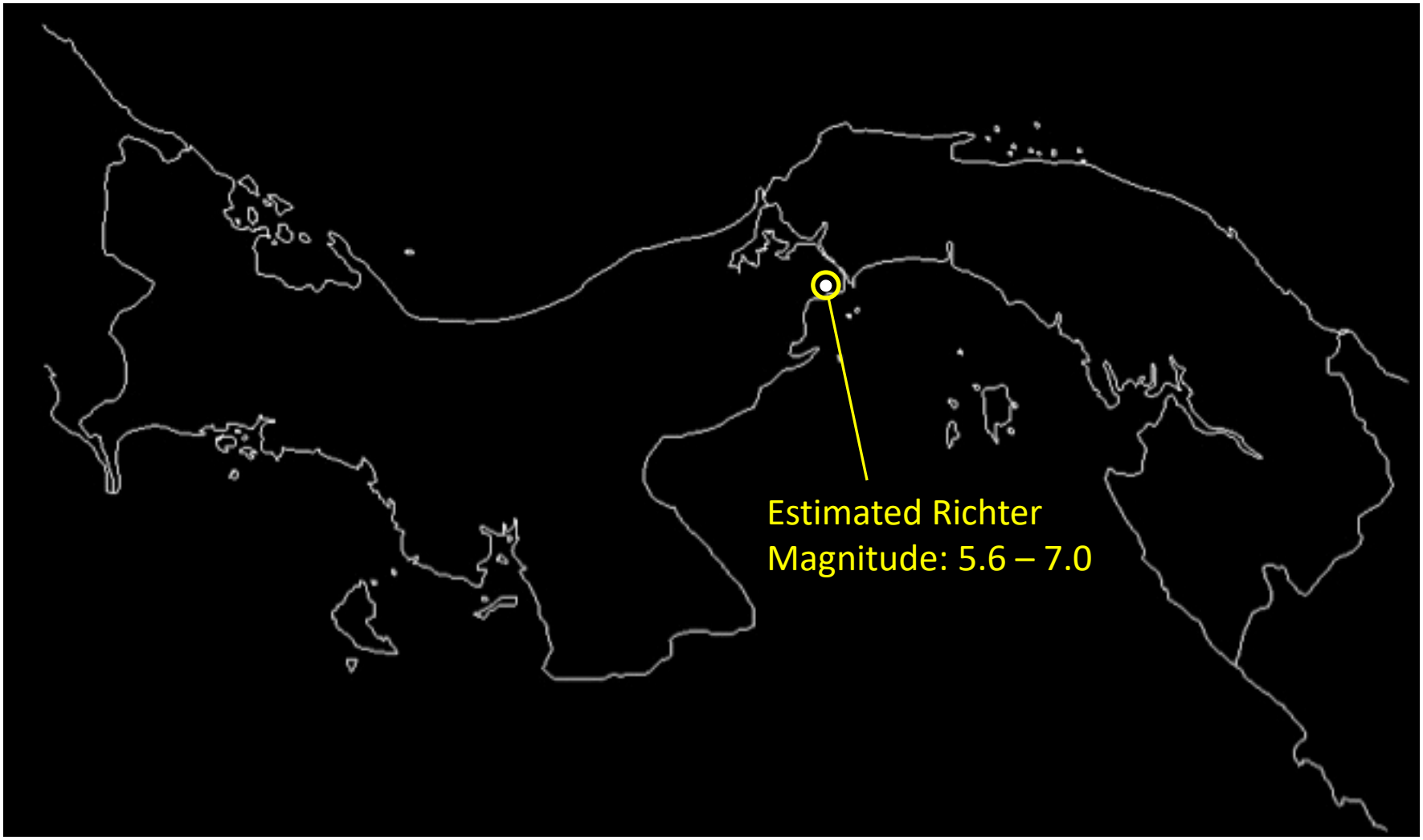


Design ship draft is 15.2 m (50’)

13,000 TEU

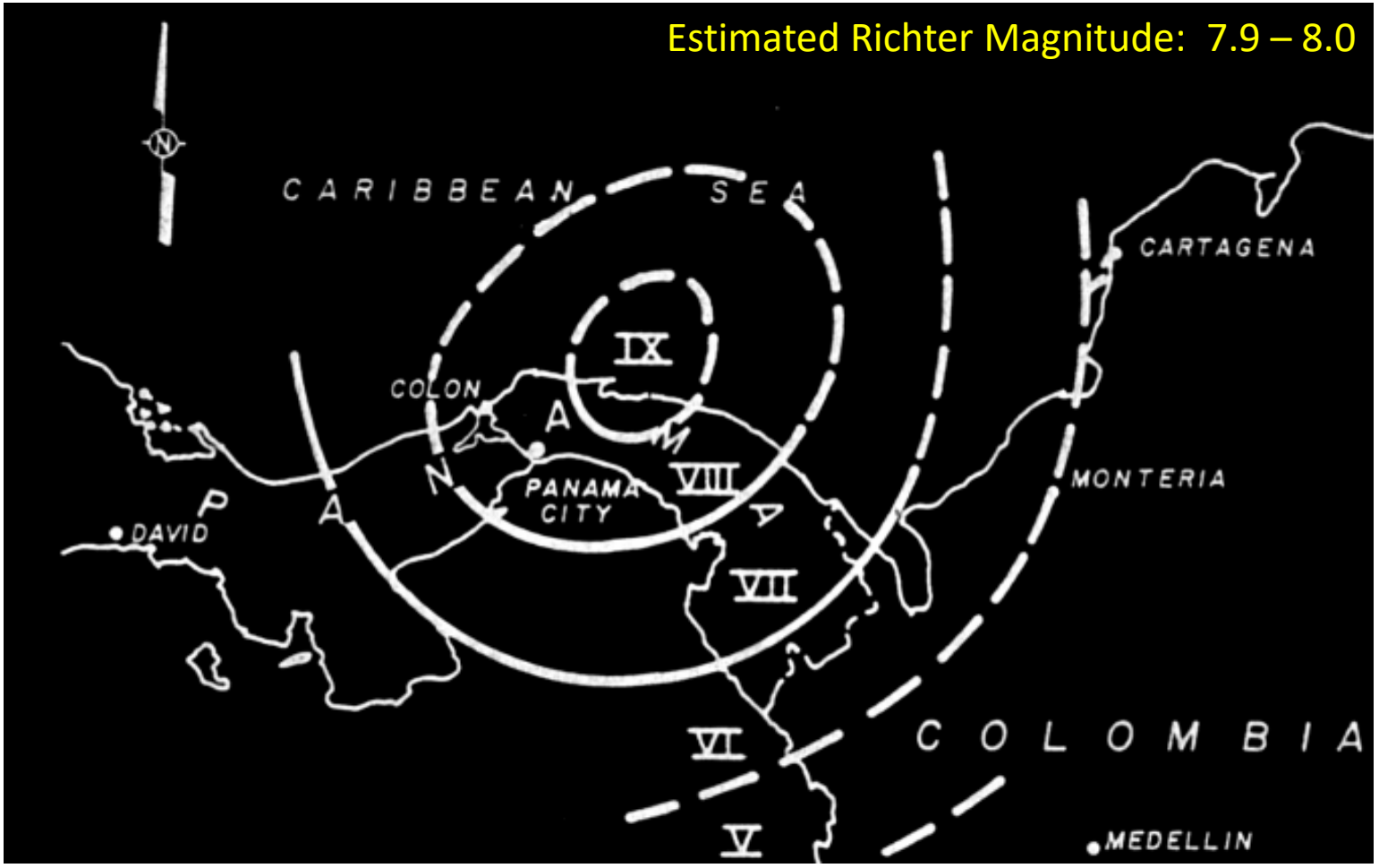
Seismic Risk

Earthquake of 2 May, 1621



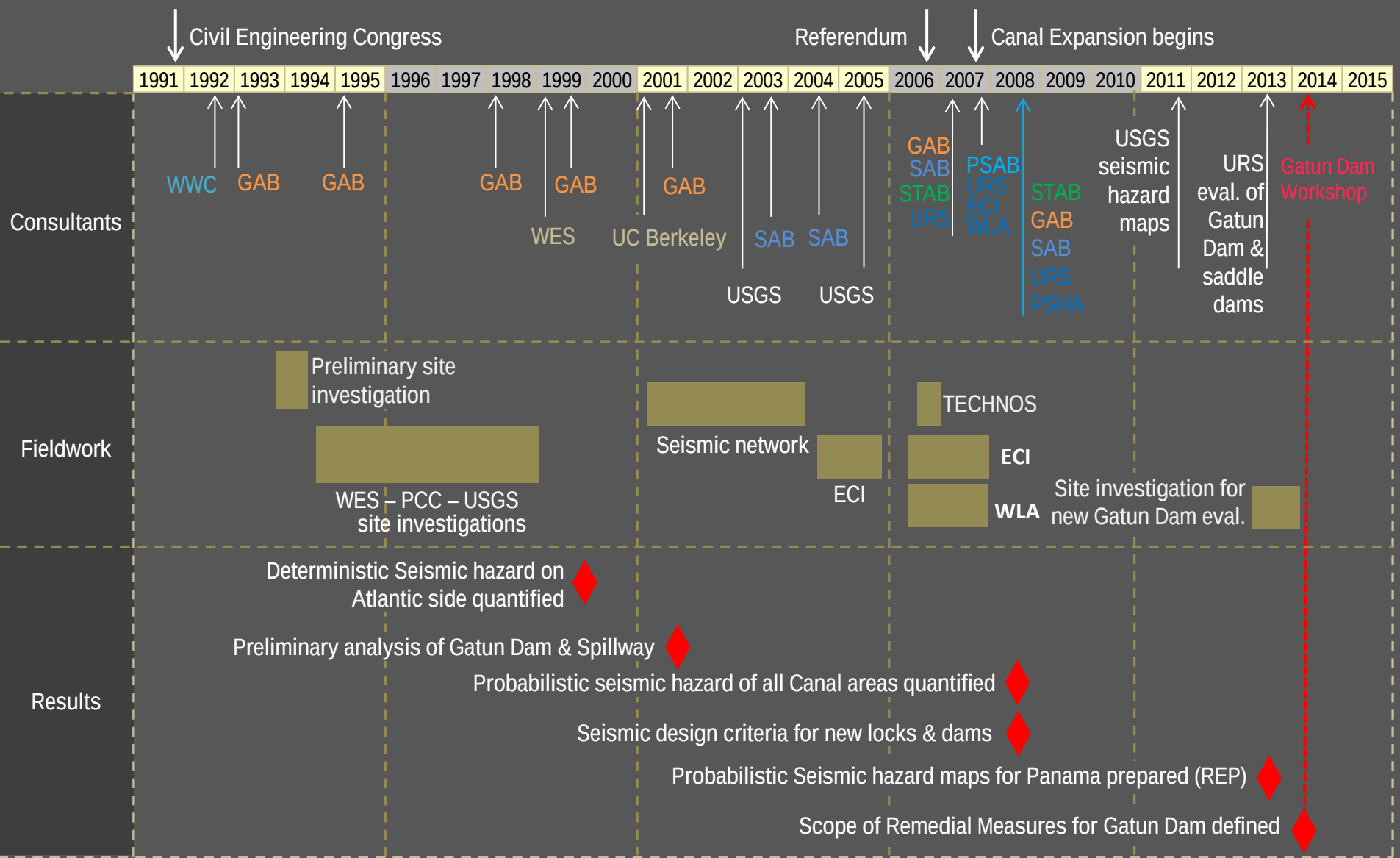
Reference: Víquez, V. and Camacho, E. (1994), “El Terremoto de Panama La Vieja del 2 de mayo de1621: Un sismo intraplaca”, Boletín de Vulcanología, OVSICORI-UNA

Earthquake of 7 September 1882



Reference: “Seismicity Evaluation Report on the Tabasará Hydroelectric Project in Western Panama”, Acres International Ltd., Niagara Falls Ontario, Canada (1981)

Chronology of investigations on seismic risk in the Canal area



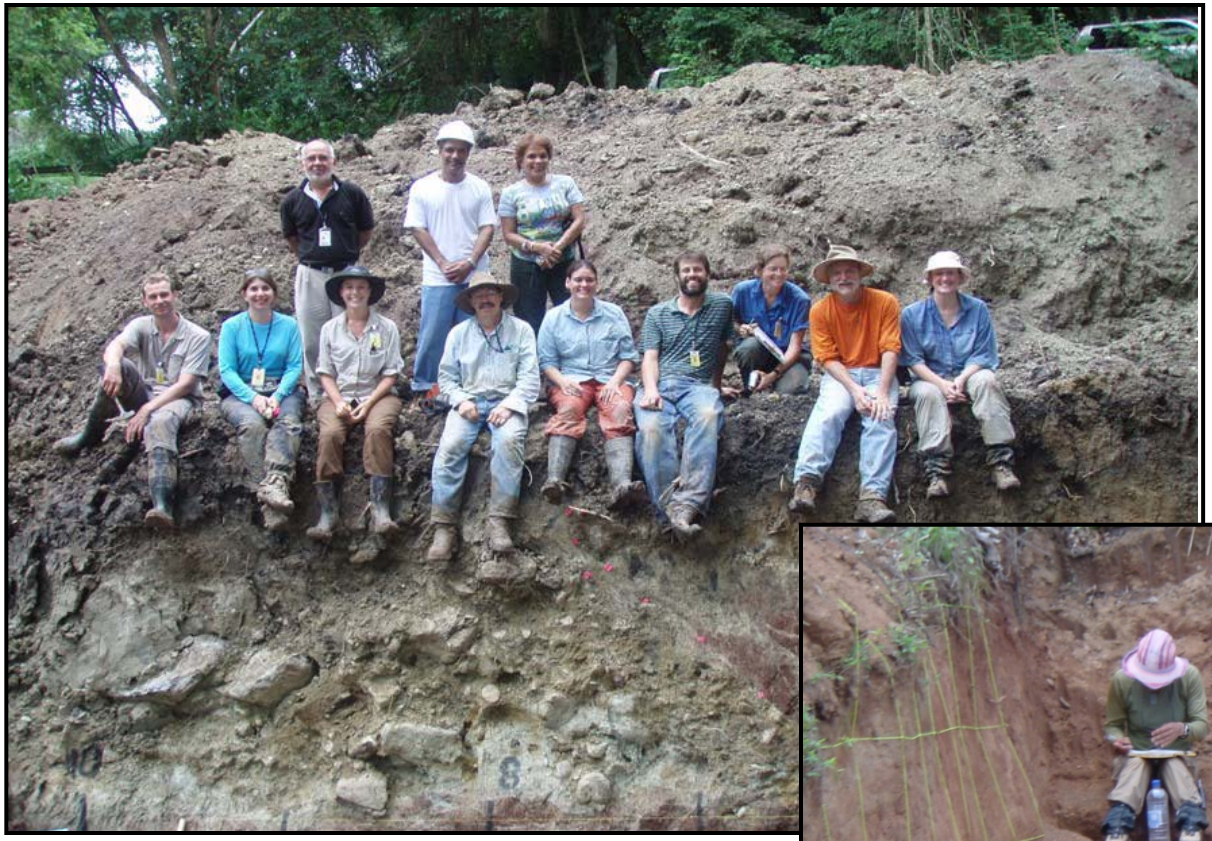
GAB: Geotechnical Advisory Board
SAB: Seismic Advisory Board
STAB: Structural Advisory Board

PSAB: Paleoseismic Advisory Board
WES: Waterways Experiment Station
USGS: US Geological Survey

URS: URS Corp
WWC: Woodward Clyde Consultants
REP: Panamanian Structural Code

ECI: Earth Consultants International
WLA: William Lettis & Associates
UC: University of California

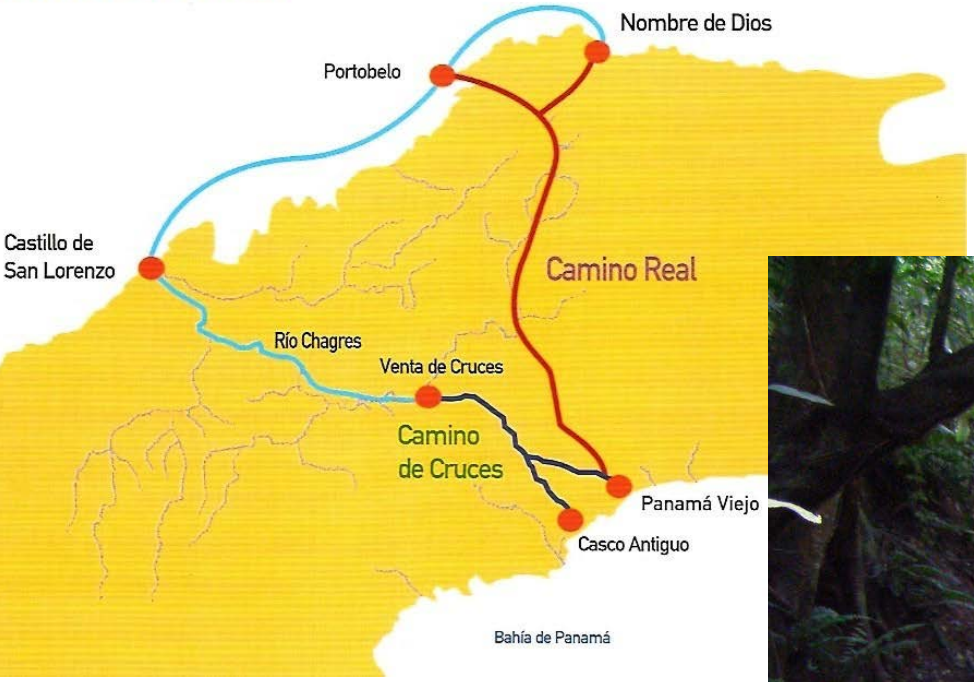
Paleoseismic Contractors



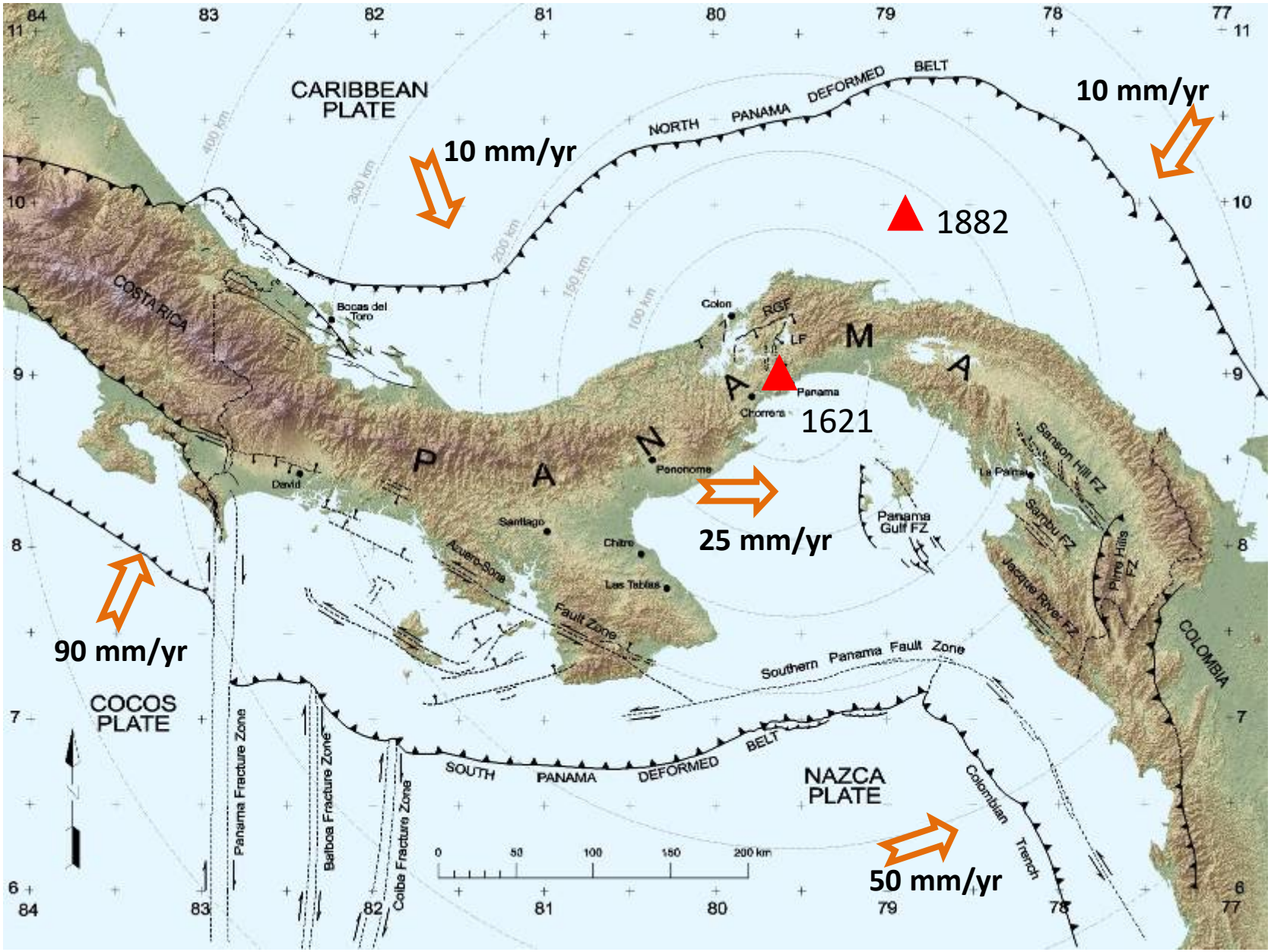
Earth Consultants International

William Lettis & Associates

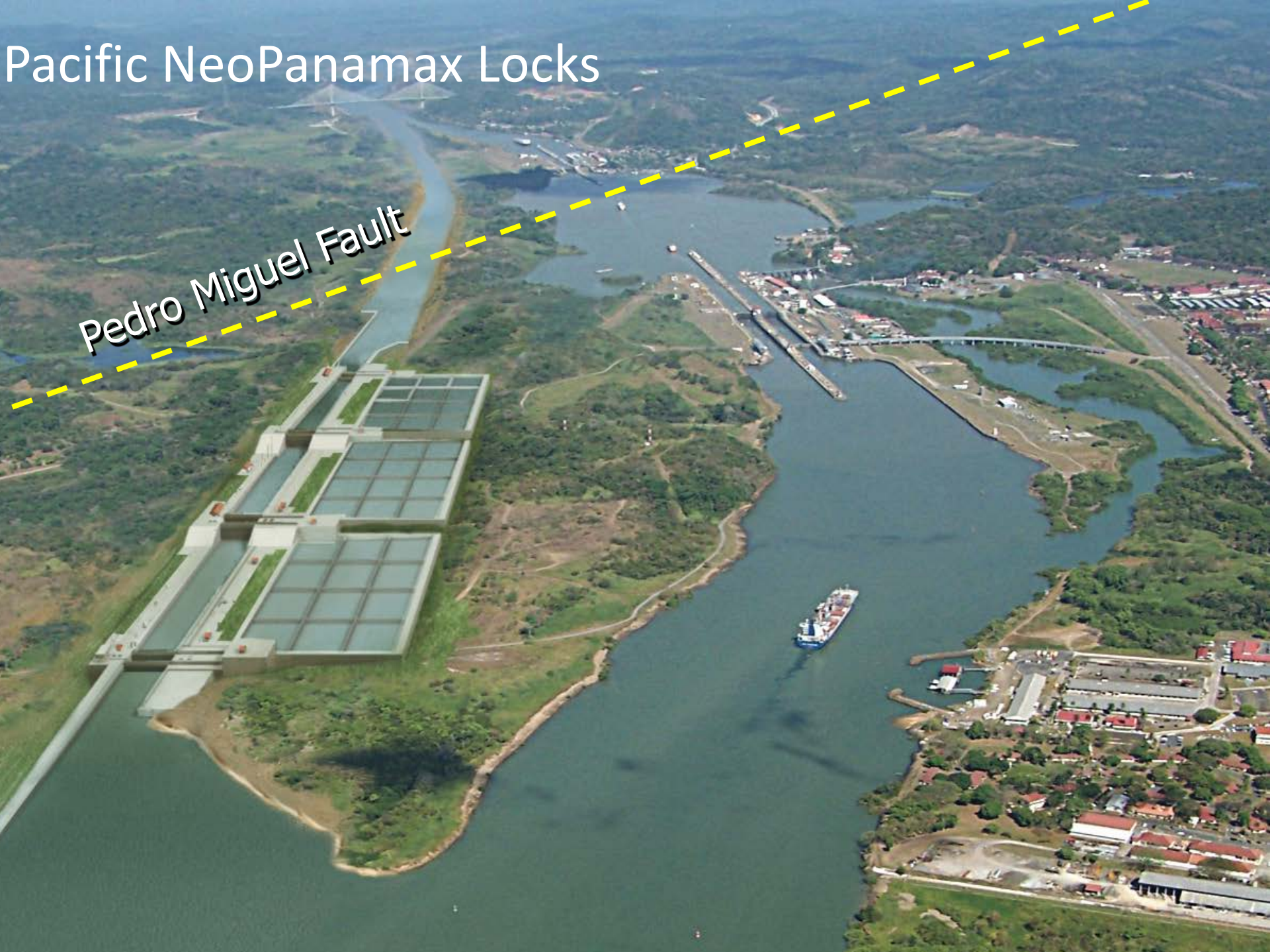
XVI Century Colonial Roads



Tectonic Map of Panama



Pacific NeoPanamax Locks



Structural Advisory Board (2007 - 2009)

Dr. Anil Chopra
Professor of Structural Dynamics, UC Berkeley

Dr. Robert Hall
Chief, Geosciences & Structures Division, WES, USACE

Dr. Sam X. Yao
Chief Engineer, Ben C. Gerwick, Inc., San Francisco, CA

Dr. Enrique Matheu
Chief, Dams Sector Branch, Department of Homeland Security, Washington, DC

Dr. José Roesset
Professor of Structural Mechanics & Dynamics, Texas A&M

Dr. Martin Wieland
Structural Engineer, Pöyry Energy Ltd., Zurich, Switzerland

Workshop to define seismic design recommendations for the design of the new locks (Jan14-18, 2008)

Design Criteria

Level of structural performance

Level of ground motion

	Completely operational (elastic range)	Repairable damages	Preserve operations
1 /475	**Design the Locks**		
1 /1,000		**Verify stability**	
1 /2,500			**Verify reservoir retention**

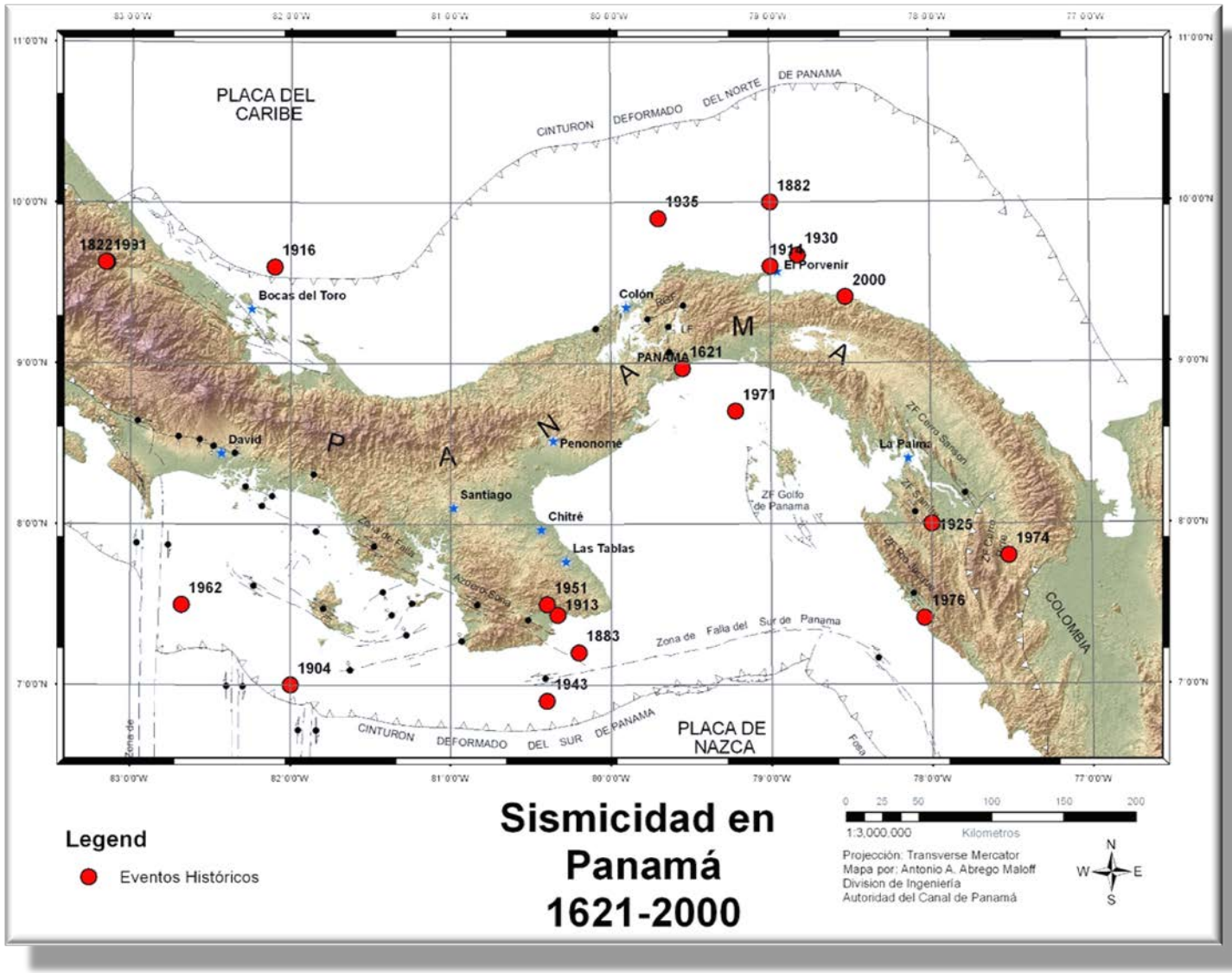
peak ground acceleration	
Pacific	**Atlantic**
0.52 g	**0.33 g**
0.72 g	**0.42 g**
0.97 g	**0.55 g**

Neo-Panamax Locks in operation, 9 years later

Further contributions from Professor Chopra

Most important Seismic Activity in Panamá

Año	Magnitud
1621, Mayo 2	> 7
1822, Mayo 7	7.5
1882, Sept. 7	7.7-8.0
1883, Feb. 5	~ 7.0
1904, Ene. 20	> 7.4
1913, Oct. 1	~ 7.0
1914, Mayo 27	6.5-7.2
1916, Abril 25	~ 7.0
1925, Mar. 29	> 7.0
1930, Mar. 7	6.0-6.5
1935, Nov. 21	~ 6.5
1943, Mayo 2	> 7.0
1951, Ene. 4	6.7, ~7.0
1962, Jul. 26	6.7-7.0
1971, Ene. 19	5.5-6.5
1974, Jul. 12	~ 7.3
1976, Jul. 11	6.8, 7.0
1991. Abril 22	7.5
2000, Feb. 26	6.1



Seismic Evaluation of the Gatun Dam Spillway

Seismic Evaluation of the Gatun Dam Spillway

Workshop at University of California at Berkeley, July 2001

1. Antonio Abrego, Fernando Guerra and Maximiliano De Puy from ACP
2. Dr. Anil Chopra
3. Dr. Yusof Ghanaat
4. Dr. Robert Hall from USACE
5. Dr. Enrique Matheu from USACE
6. Donald Yule from USACE

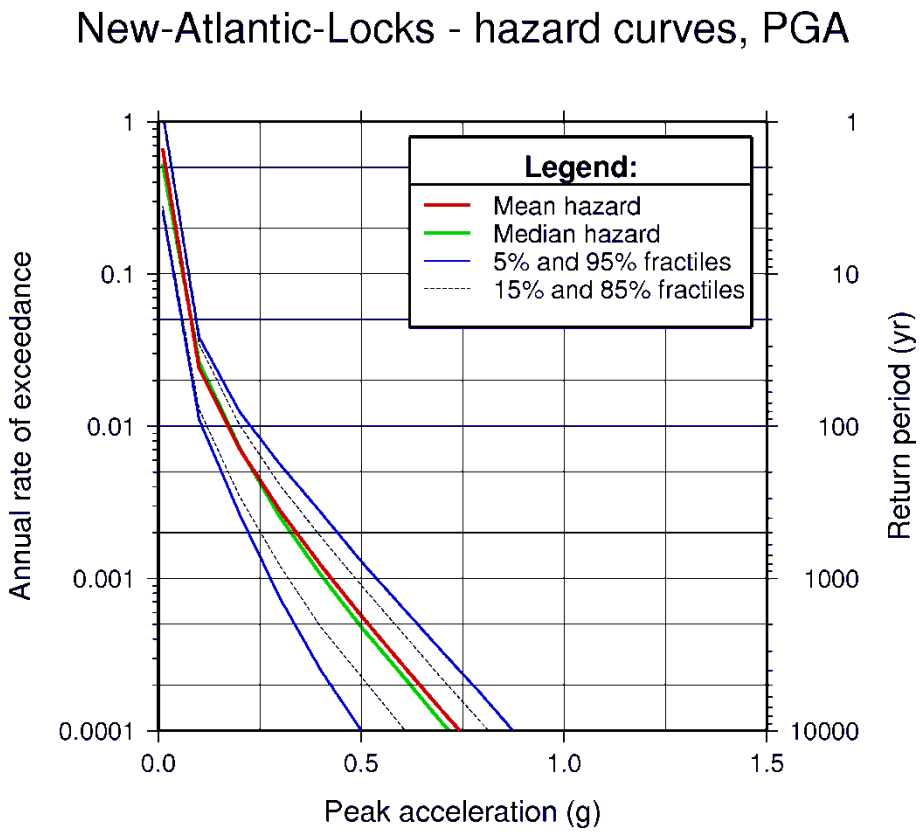
Panama City (2015)

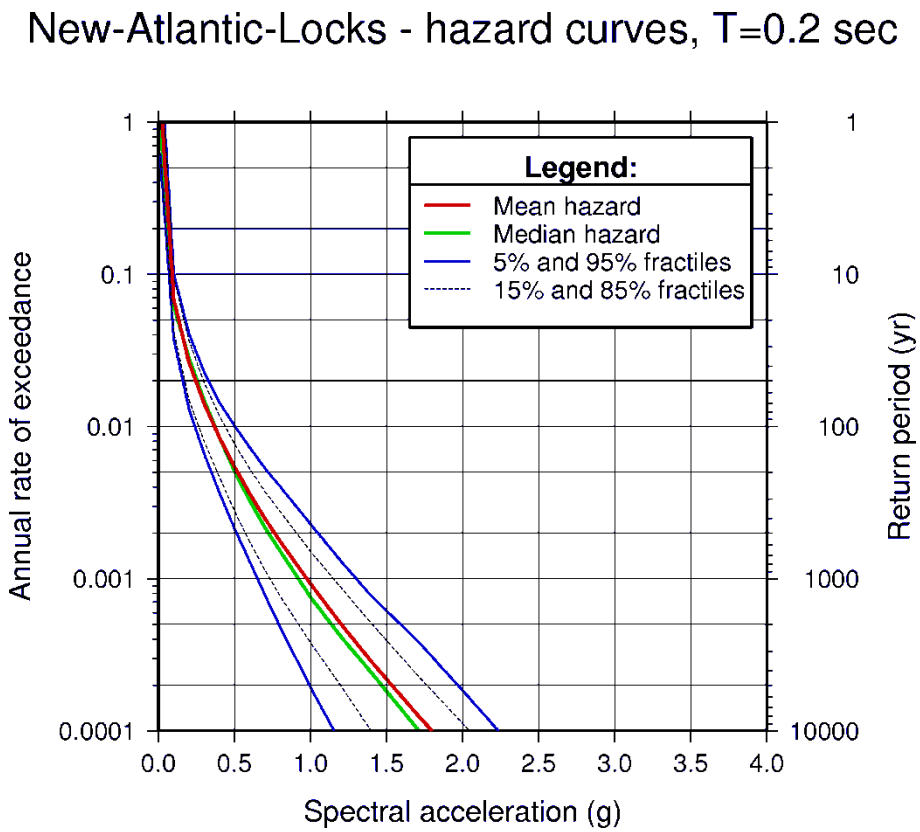
Panama City (2015)

Evolution of Structural Design Codes in Panama

Code	Author	Year	Area covered
Building Regulations for the Canal Zone	Isthmian Canal Commission	1907	Canal Zone
Building Regulations for the Canal Zone	The Panama Canal	1915	Canal Zone
Building Regulations for the Canal Zone	Canal Zone Government	1957	Canal Zone
Seismic Code for Panama	Technical Board of Engineers and Architects	1976	Panama
Panamanian Structural Design Code	Technical Board of Engineers and Architects	1984	Panama
Panamanian Structural Design Code	Technical Board of Engineers and Architects	1994	Panama
Panamanian Structural Design Code	Technical Board of Engineers and Architects	2004	Panama
Panamanian Structural Design Code	Technical Board of Engineers and Architects	2014	Panama

Panama Canal Seismic Characterization





Transfering Seismic Findings to Local Technical Community

Workshop at Degenkolb Engineers in San Francisco, January 2009

1. Anil Chopra from Structural Advisory Board (STAB) of ACP
2. Fernando Guerra and Daniel Ulloa from ACP
3. David Bonneville, Roger Parra and Chris Poland from Degenkolb Engineers
4. Mark Petersen from USGS
5. Ernesto Ng from Comité del Reglamento Estructural de Panamá (REP)

Transfering Seismic Findings to Local Technical Community

Workshop at ACP, June 2010

1. Anil Chopra from Structural Advisory Board (STAB) of ACP
2. David Bonneville, and Chris Poland from Degenkolb Engineers
3. Panamanian Structural Code (REP) Committe members

Transfering Seismic Findings to Local Technical Community

Transfering Seismic Findings to Local Technical Community

New Gatún Lake Spillway at ACP, 2012

- The need for a new spillway was identified since the 1930's because its spilling capacity was seemed to be insuficcient.

- In 1945, E. Randolph began studying a new structure.

- As the maximum operational lake level was increased, as part of the Canal Expansion Program, a new spillway was deemed more urgent.

New Gatún Lake Spillway at ACP, 2012

Location proposed by Randolph (1945)

New Gatún Lake Spillway at ACP, 2012

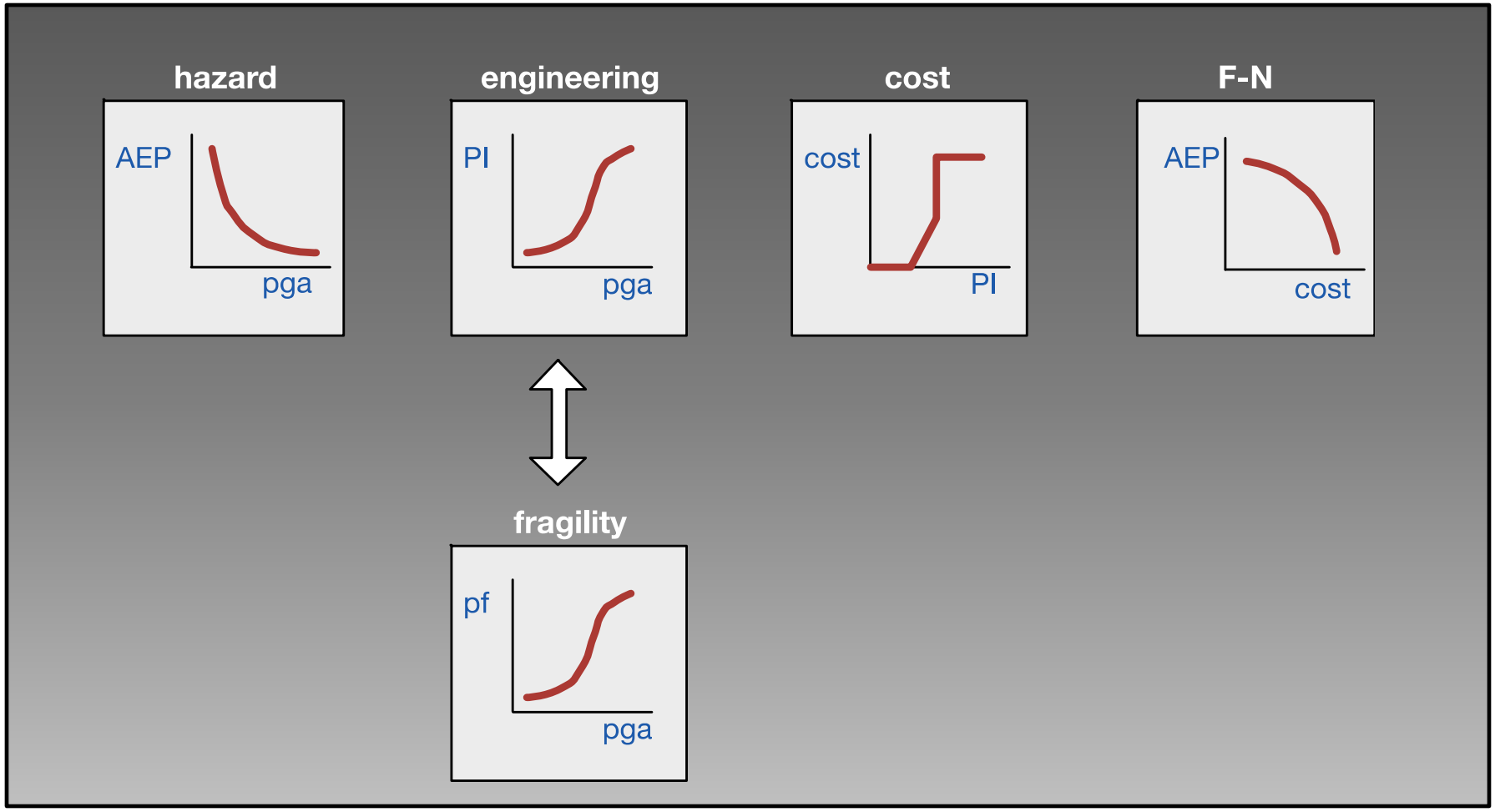
- Dr. Chopra advised ACP on the preparation of the Design Specifications.
- Dr. Chopra recommended the incorporation of Larry Nuss from the USGS to the ACP support team for the project due to his vast experience on this matter.
- Dr. Chopra was a member of the Design Peer-Review Board for the project.

Panama Canal Physical Risk Management, 2011-present

Principal Physical Risks

Type	Catastrophic Natural Risks	Chronic Natural Risks	Anthropogenic Risks
Main drivers	• Meteorological • **Seismic**	• Time • Degradation from use	• Human activities
Events	• Floods • Earthquakes • Landslides • Droughts	• Erosion • Sedimentation • Corrosion • Aging	• Terrorism • Sabotage • Accidents

Panama Canal Physical Risk Managenent, 2011-present



AEP = annual exceedance probability
PI = Performance Indicator
pf= probability of failure

Panama Canal Physical Risk Managenent, 2011-present

- ACP has implemented an Enterprise Risk Management Program (ERM)
- ACP Engineering Division has supported the ERM by providing input on Canal Infrastructure Physical Risks
- Dr. Chopra has helped the Physical Risk characterization work, giving advice on the appropriate structural analysis methods we should use.
- Dr. Anil Chopra recommended potential consultants, with specialized expertise on the analyses of existing concrete massive structures.

Professor Chopra´s contributions to

The Panama Canal

and the

Panamanian Structural Design Code

Thank you, Anil