A WORLDWIDE AND UNIFIED DATABASE OF SURFACE RUPTURES (SURE) FOR FAULT DISPLACEMENT HAZARD ANALYSES

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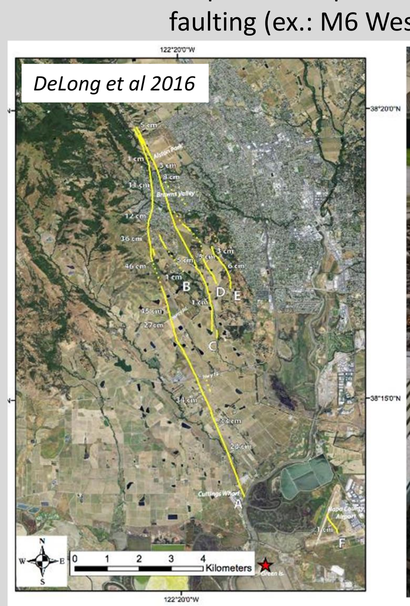
Why?

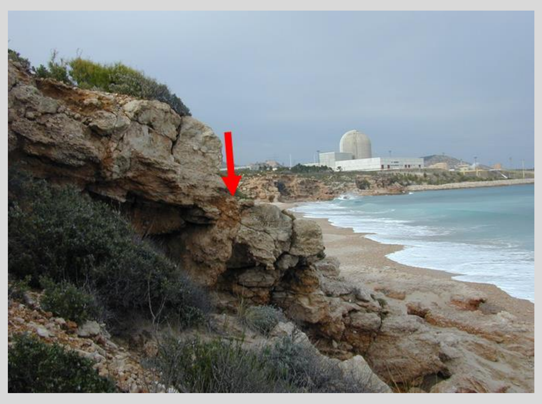
- Surface faulting is a threat for infrastructures, both on main/primary and distributed segments
- Fault Displacement Hazard Analysis is developing (mainly following Probabilistic Approach) for critical facilities
- Needs for reliable and robust databases (displacement attenuation, scaling laws, ec)

Challenges

Evaluate the finite displacement the fault can produce
- Pipeline designed to withstand 20 feet of dextral offset
- 2002 M7.9 Denali earthquake rupture: 14 feet at that point

Moderate earthquakes can produce primary and distributed faulting (ex.: M6 West Napa earthquake, 2014)

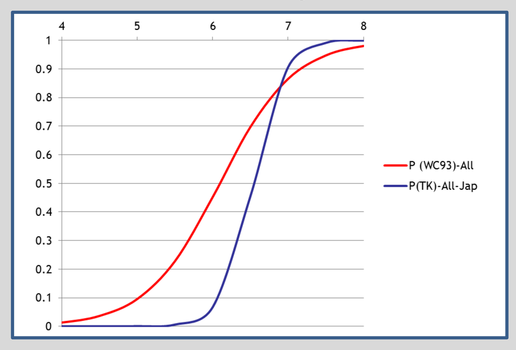




Low slip-rate faults may require a Probabilistic analysis for critical facilities

State-of-the-art

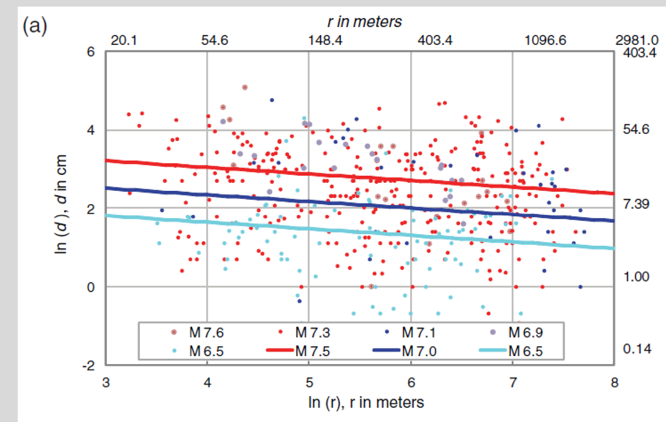
Probability of Surface faulting



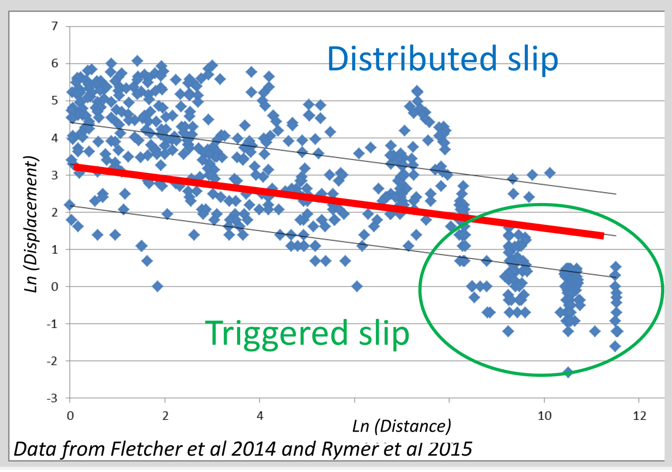
Could this probability difference be controlled by detection capacity of geologists?
Recent techniques allow the recognition of coseismic features in many environments

From Wells Coppersmith 1993
And Takao et al. 2013

Probability distribution of amount of slip vs distance (distributed rupture)



- Petersen et al (2011) compiled a series of data for 9 large strike-slip earthquake (M>6.5) and produced regressions for distributed rupture
- Note that regressions are extrapolated to low M in PFDHA (e.g. Diablo Canyon , Krsko NPPs)



Data from Fletcher et al 2014 and Rymer et al 2015

Prediction vs Observation for M7.2 El Mayor Cucapah event →
Under-estimated mean (and uncertainty) value for distributed slip

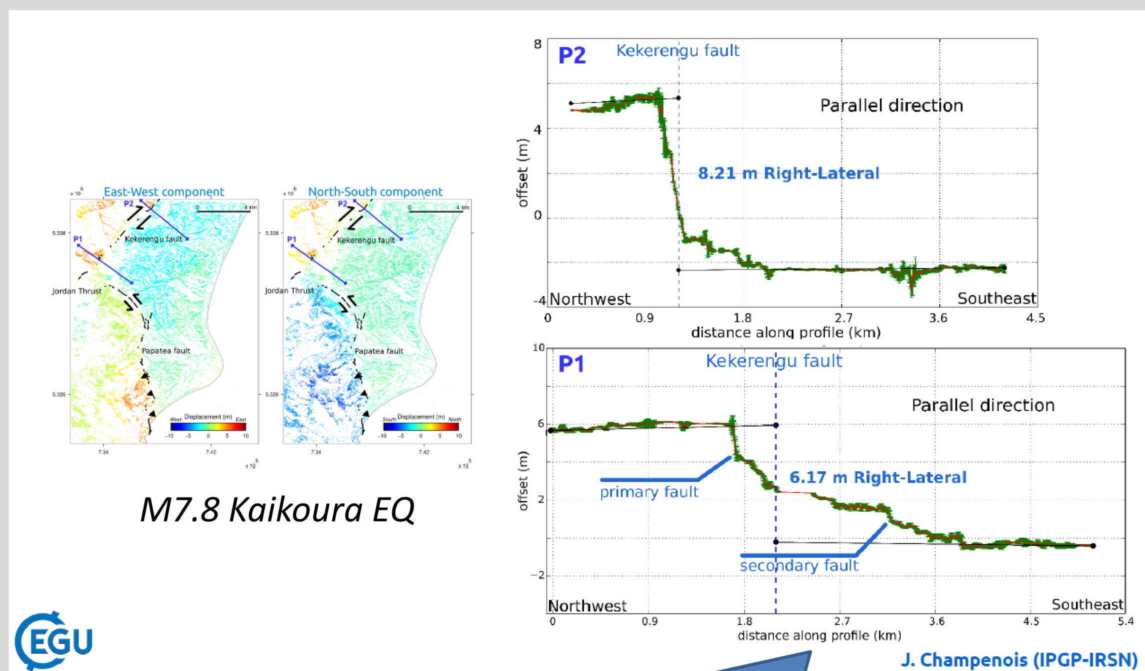
New database required - SURE

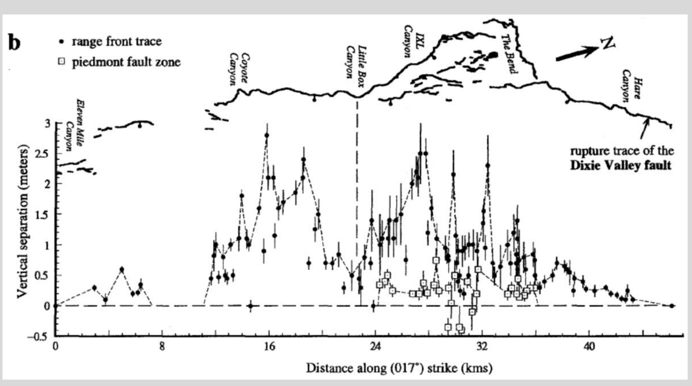
How?

Current databases contain few cases, with limited magnitude range, limited parameters are considered

1. Unify the existing datasets
2. Increase the number of cases, the amount of data using modern techniques
3. Include relevant description parameters

High resolution optical correlation to provide dense measurements





Structural complexity

- Ruptures of 1954 Dixie Valley (Caskey et al 1996)
- Note most distributed faults occur in fault bend, a stationary feature that will persist. Elsewhere distributed faults are rare

Merging New & Old Cases

New parameters

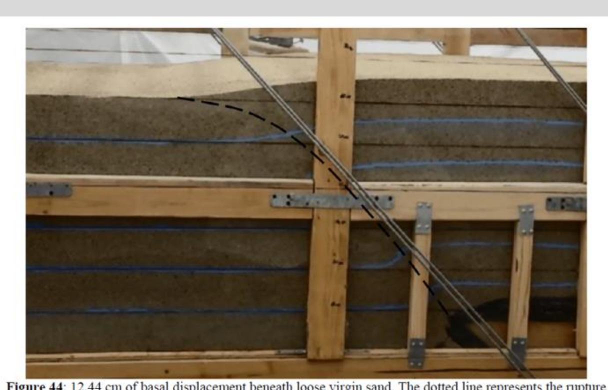


Figure 44: 12.44 cm of basal displacement beneath loose virgin sand. The dotted line represents the rupture plane. The edges have been cropped for clarity.

Table 8: Basal displacement required for surface rupture given material type, relative stiffness, state and shear wave velocity

Run	Material Type	Relative Stiffness	Material State	Shear Wave Velocity (m/s)	Basal Displacement Required for Surface Rupture (cm)	h/H
1.0	Sand	Loose	Virgin	77.0	12.44	0.147
1.1	Sand	Loose	Disturbed	77.0	2.19	0.025
2.0	Sand	Dense	Virgin	101.4	4.01	0.047
2.1	Sand	Dense	Disturbed	101.4	0.50	0.0059
3.0	Clay	Stiff	Virgin	41.8	5.73	0.068
3.1	Clay	Stiff	Disturbed	41.8	1.15	0.014
4.0	Clay	Soft	Virgin	23.65	8.37	0.097
4.1	Clay	Soft	Disturbed	23.65	3.76	0.044

Stanton (2013) sandbox experiments
Displacement at depth to product surface displacement vary with lithology, stiffness and deformation history

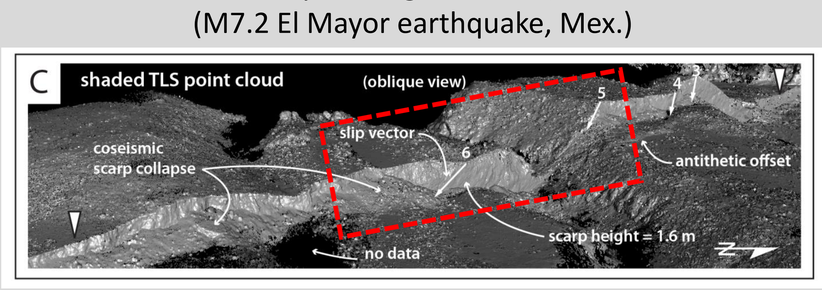
Superficial Geology

Lithology, stiffness and deformation history control surface displacement

M6.5 Norcia Earthquake, Italy
Surface rupture amplitude is dimished in the presence of alluvium

Modern & Vintage data

Terrestrial LiDAR can yield huge datasets, with uncertainties (M7.2 El Mayor earthquake, Mex.)



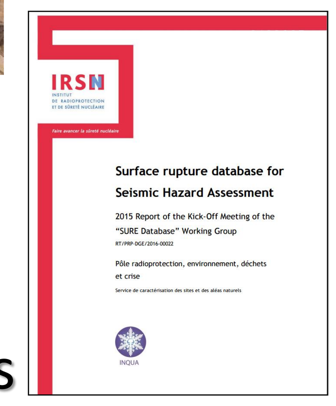
Gold et al. 2013

Field measurement

With whom?

PATA Days

INQUA



Workshops

IAEA
International Atomic Energy Agency

Pending TECDOC

Consultancy Meeting of Working Group 1.3 "Fault Displacement Hazard Assessment"

IRSN-IPGP & IRSN-U.Chieti collaborations

IRSN/IPGP & IRSN/UdA funded projects (ECR, PhD) to enrich dataset and improve methodology

→ See Fiia Nurminen's contribution

FDH Initiative

https://www.risksciences.ucla.edu/nhr3/projects/fdhi

Towards A New Model Database for Next-Generation FDHA, a flexible and relational database that can accommodate both vintage data and newer datasets

How it looks like…

Submitted to Seismo. Res. Letters (2019)

Structure of database
-
3 Flatfiles and related Shapefiles

Earthquake table

Field Name	Type
ID	
Magnitude	real
Depth	real
Focal mechanism	real
reference	text
SRL from Geology	real
Reference	text
SRL from Geodesy	real
Reference	text
Deep Rupture length	real
Fault Width	real
Average displacement	real
reference	text
Seismo layer thickness	real
reference	text
Structural context	text
Inversion tectonics	text
Morphoclimatic context	text
Quality ranking	integer

Segment table

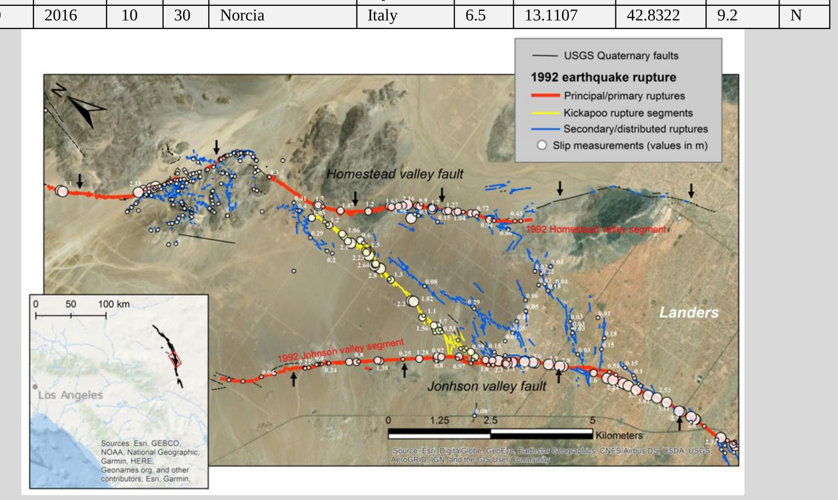
	Field Name	Type	Required
	ID		yes
	Map scale	real	
Fault section parameters	length	real	yes
	strike (0-360°)	real	yes
	mean dip	real	yes
	fault tip dip	real	
	fault-pattern complexity	text	
	Observer/Author ranking		
Primary vs Distributed)	Paleo-events		
	Slip rate	real	
	Compiler section		
	Origin	text	yes
	Compiler ranking	text	yes

	Field Name	Type	Required
Basic info	ID	integer	yes
	Date	date/time	
	reference	text	
	Observer	text	yes
	Description	text	
	Latitude	real	yes
	Longitude	real	yes
Displacement and errors	lateral	real	
	uncertainty horizontal (+)	real	
	uncertainty horizontal (-)	real	
	Max horiz measurement	real	
	Min horiz measurement	real	
	Large-aperture offset	real	
	Width	real	
	Capture 100% deformation? (Y/N)		
	vertical	real	
	uncertainty horizontal (+)	real	
	uncertainty horizontal (-)	real	
	Max vert measurement	real	
	Min vert measurement	real	
	Large-aperture offset	real	
	Aperture Width	real	
	Capture 100% deformation? (Y/N)		
	upside	text	
	Net Slip	real	
	uncertainty (+)	real	
	uncertainty (-)	real	
	Max measurement	real	
	Min measurement	real	
	Slip vector inclination (°)	real	
	Shortening	real	
	Observer/Author ranking	text	

Observation table

45 cases;
40,000 segments;
15,000 obs.

IdE	YYYY	M	DD	Name	Region	Mw	Longitude	Latitude	Depth	FM
18720326	1872	03	26	Owens Lake	USA	7.45	-118.1	36.65		SS
18870503	1887	05	03	Sonora	Mexico	7.5	-109.25	30.8		N
18911028	1891	10	28	Nobi	Japan	7.4	136.6	35.6	10	SS
18960831	1896	08	31	Rikuu	Japan	6.7	140.7	39.5	10	R
19110103	1911	01	03	Chon-Kemin	Kaz./Kyr.	7.7	78.53	43.013	20	R
19151003	1915	10	03	Pleasant Valley	USA	6.8	-117.654	40.258	10	N
19181111	1918	11	11	Omachi	Japan	6.4	137.3	36.1	10	R
19270307	1927	03	07	North Tango	Japan	7.1	135.0129	35.6317	10	SS
19301125	1930	11	25	North Izu	Japan	6.9	139.1295	35.0497	15	SS
19380529	1938	05	29	Kussharo	Japan	5.8	145.0109	42.9999	0	SS
19390501	1939	05	01	Oga	Japan	7	139.771	39.979	10	SS
19430910	1943	09	10	Tottori	Japan	7	133.9932	35.4481	15	SS
19440115	1944	01	15	La Laja	Argentina		-68.491	-31.496	15	R
19450112	1945	01	12	Mikawa	Japan	6.7	137.0638	34.6123	10	R
19541216	1954	12	16	Fairview Peak	USA	7.1	-117.981	39.346	10	N
19541217	1954	12	16	Dixie Valley	USA	6.6	-117.704	39.207	15	N
19590130	1959	01	30	Deshibori	Japan	6	144.5088	43.3708	25	SS
19590818	1959	08	18	Hebgen Lake	USA	7.2	-110.891	44.63	10	N
19680409	1968	04	09	Borrego M.	USA	6.6	-116.234	33.058	10	SS
19710209	1971	02	06	San Fernando	USA	6.7	-118.4126	34.2740	8.4	R
19740508	1974	05	08	Izu Penin. Bay	Japan	6.4	138.753	34.5719	10.3	SS
19780114	1978	01	14	Izu Offshore	Japan	6.6	139.2254	34.8023	24.4	SS
19791015	1979	10	15	Imperial Valley	USA	6.5	-115.374	32.752	10	SS
19800525	1980	05	25	Mammoth L.	USA	6.2	-118.908	37.53	10.2	N
19831028	1983	10	28	Borah Peak	USA	6.9	-113.796	44.092	10	N
19840913	1984	09	13	Nagano Pref.	Japan	6.2	137.4871	35.7824	17.9	SS
19870302	1987	03	02	Edgecumbe	New Z.	6.5	176.80	-37.89	10	N
19871124	1987	11	24	Supersition H.	USA	6.5	-115.886	33.011	10	SS
19920628	1992	06	28	Landers	USA	7.3	-116.557	34.188	10	SS
19950116	1995	01	16	Hyogo Pref.	Japan	6.9	135.0409	34.554	19	SS
19980903	1998	09	03	Iwate Pref.	Japan	5.8	140.7555	39.743	7.6	R
19990817	1999	08	17	Izmit	Turkey	7.6	29.979	40.807	15	SS
19991016	1999	10	16	Hector Mine	USA	7.1	-116.387	34.539	20	SS
20001006	2000	10	06	Tottori Pref.	Japan	6.7	133.157	35.38	0.6	SS
20021103	2002	11	03	Denali	USA	7.9	-147.597	63.512	12.5	SS
20041023	2004	10	23	Niigata Pref.	Japan	6.6	138.7706	37.3032	8.5	R
20080613	2008	06	13	Iwate-Miyagi	Japan	6.9	140.7365	39.1514	11.6	R
20090406	2009	04	06	L'Aquila	Italy	6.3	13.353	42.368	10	N
20100326	2010	03	26	Pisayambo	Ecuador	5	-78.32	-1.24	10	SS
20100404	2010	04	04	El Mayor	Mexico	7.2	-115.266	32.348	10	O
20100903	2010	09	03	Darfield	New Z.	7.2	172.17	-43.53	11	SS
20140824	2014	08	24	Napa	USA	6	-122.312	38.215	11.1	SS
20141122	2014	11	22	Nagano Pref.	Japan	6.2	137.888	36.641	9	R
20160415	2016	04	15	Kumamoto	Japan	7	130.77	32.84	12.9	SS
20161030	2016	10	30	Norcia	Italy	6.5	13.1107	42.8322	9.2	N



Potential Interactions with Fault2SHA

- SURE contain data for Empirical Scaling Relationship Generation and for Validation of Rupture Modeling Results
- Earthquake Rupture Forecast Models can be used in PFDHA (e.g. Biasi, 2016: Performance-Based PFDHA Using the Third Uniform California Earthquake Rupture Forecast, Menlo Park Workshop)