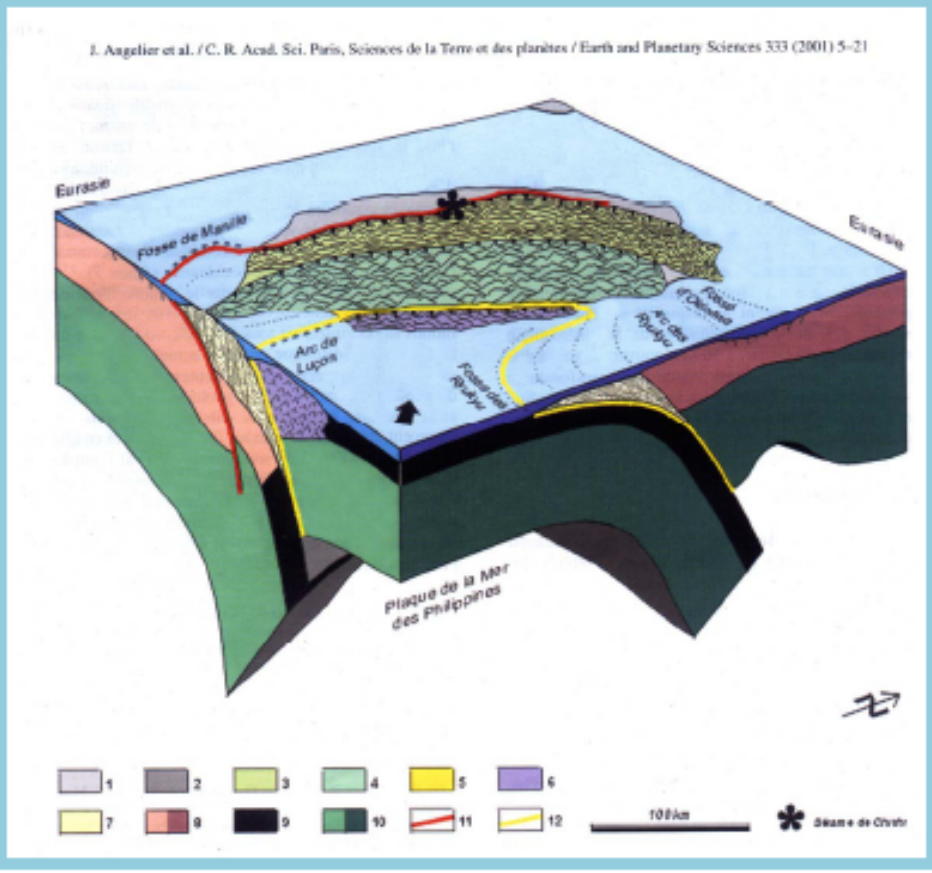
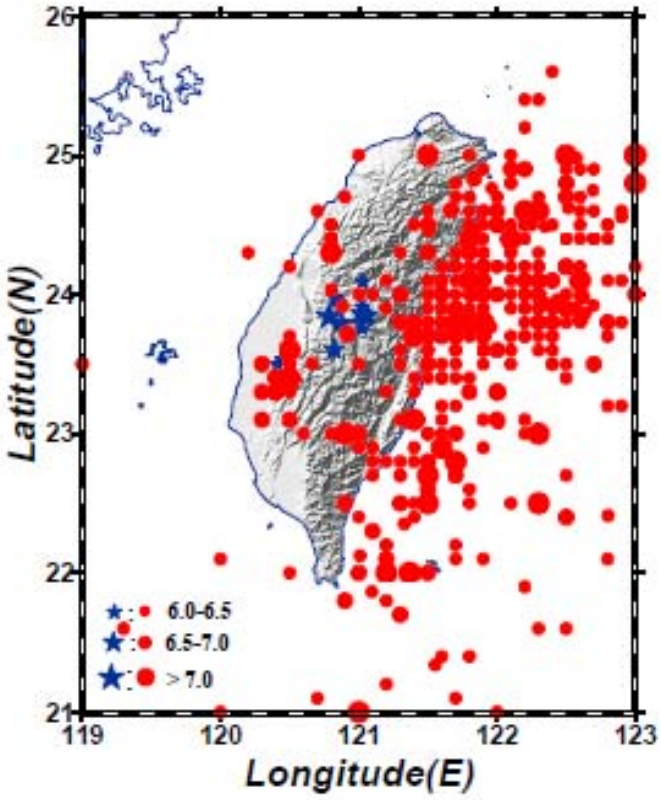
Engineering Geology and Landslide Hazard in Taiwan

Meei-Ling Lin
Department of Civil Engineering
National Taiwan University



Topography and Active Faults in Taiwan

- The historical earthquakes with magnitude greater than 6 from 1900 to 1999. (Shin, 1999)



The Chi-Chi Earthquake

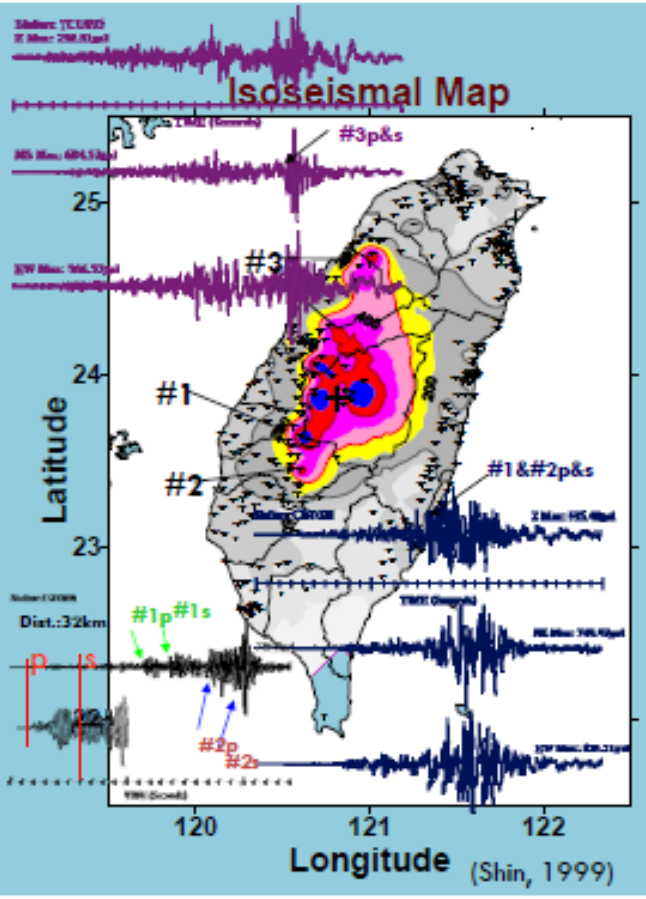
- Near field data (CWB)
  - Time: 1999/09/21 01:47:15.9 (GMT+8)
  - Local Magnitude: 7.3
  - Epicenter:120.82E, 23.85N
  - Depth: 8km

Moment Magnitude: 7.6 by long range data

Number of death: 2505

Total economic loss: US$34.2 billions

- The isoseismal map with the three triggered events of the Chi-Chi earthquake

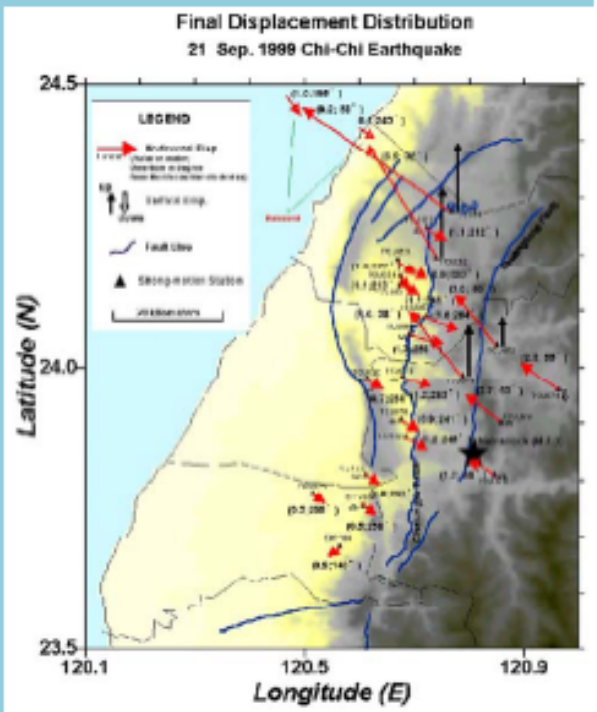


(Shin, 1999)

GPS Displacement Observation after Chi-Chi earthquake

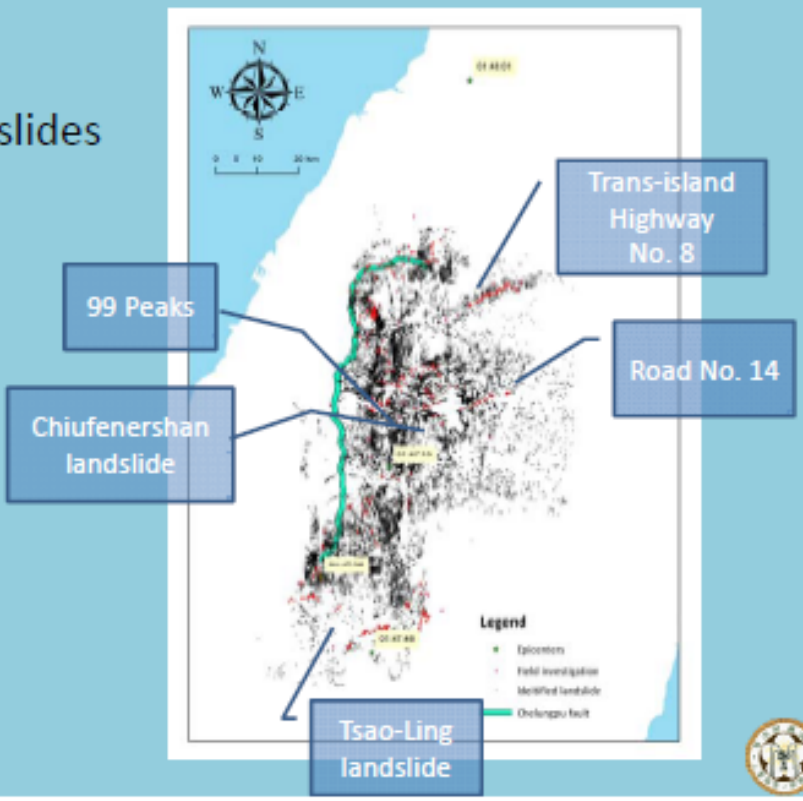
maximum horizontal ground displacement: 9.8m
Maximum vertical displacement: 6m.

(Huang et al.,1999)

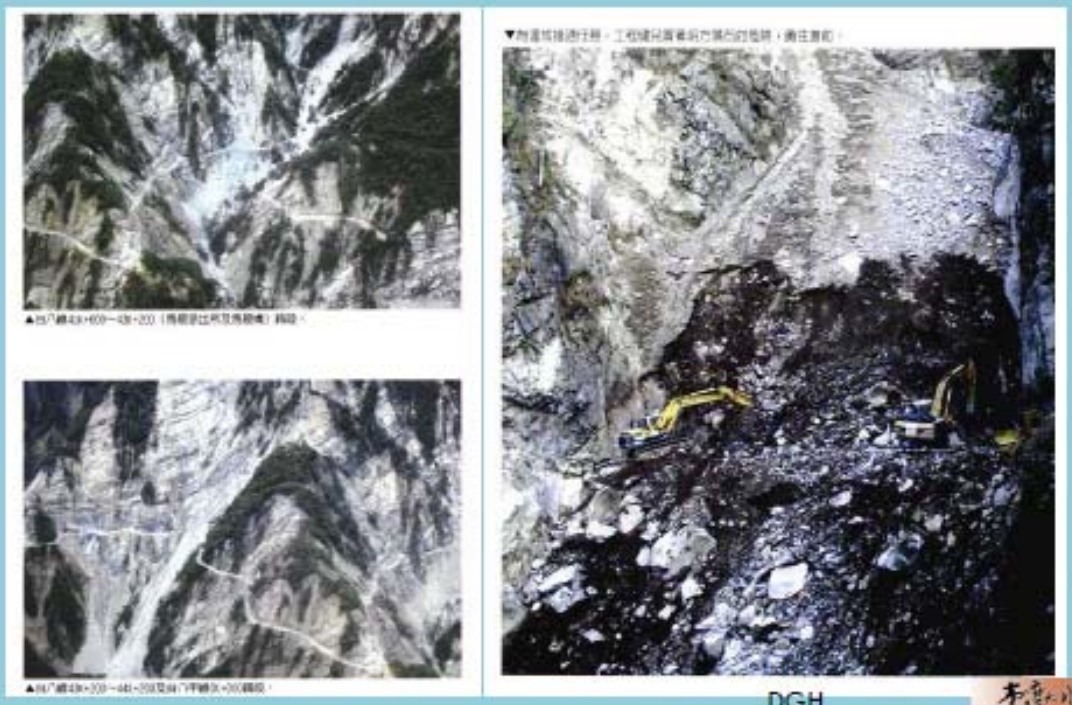


Landslides Caused by the Chi-chi Earthquake

- Over 20,000 landslides were identified

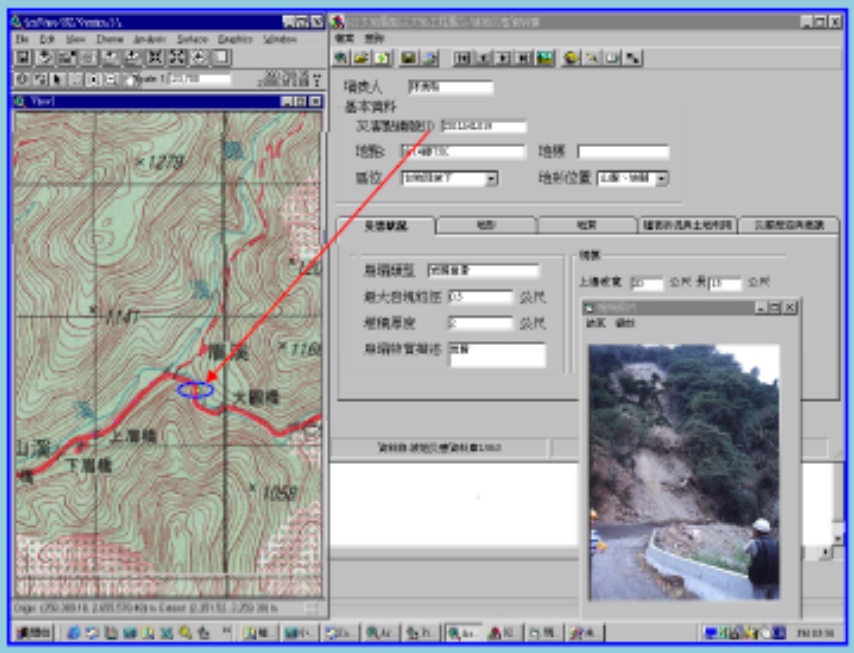


Trans-island Highway No.8



DGH

Database of Geotechnical Hazard Information System

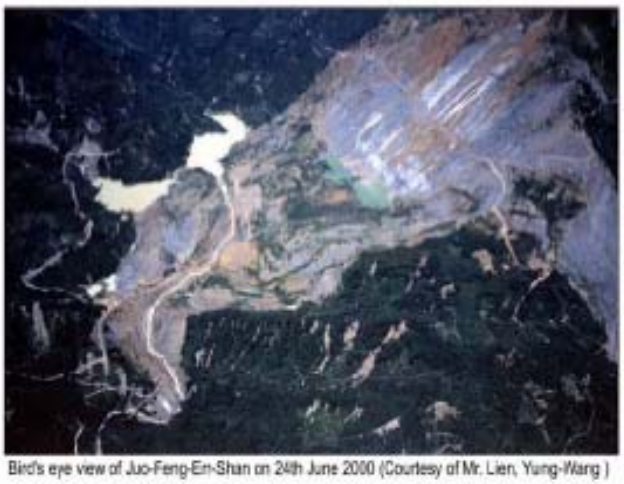


Database of:

- **Landslides**
- **Foundation failures**
- **Liquefaction**

Chiufenershan Landslide

- Sliding area: 195 hectare
- Debris volume: 40,000,000 cubic meter
- 39 people killed



Bird's eye view of Juo-Feng-En-Shan on 24th June 2000 (Courtesy of Mr. Lien, Yung-Wang)

Tsao-Ling Landslide

Courtesy of Professor J.J. Hung

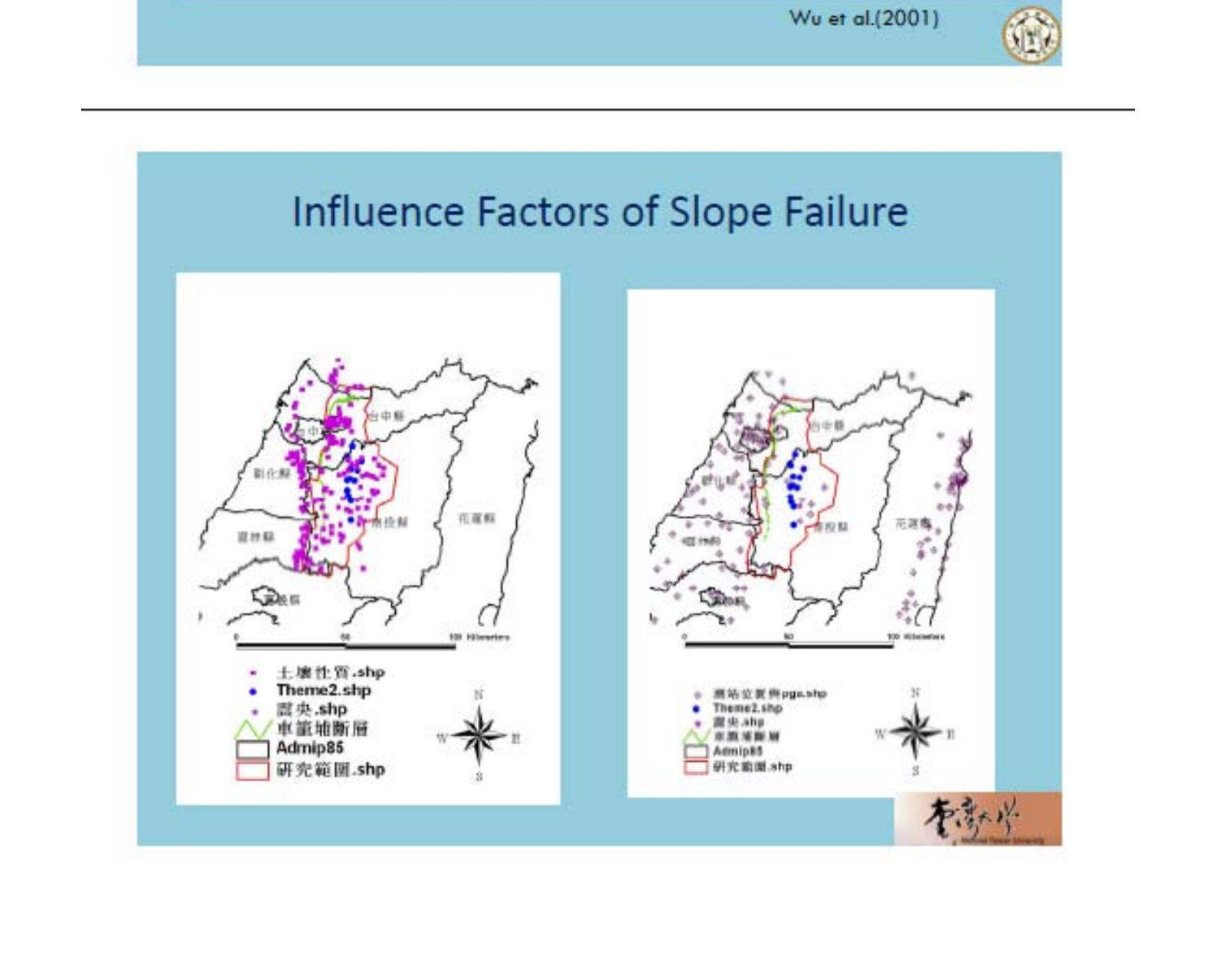
- Sliding area: 400 hectare
- Block length: 5km (upstream to downstream)
- Debris volume: 120,000,000 cubic meter
- 29 people killed

Figure Bird's eye view of Dam-up lake, Tsao-Ling village, and the landslide area, looking to to the north-west direction. (Photo taken on 29th June 2000 by Mr. Lien, Yung-Wan

Tsao-Ling Landslide History

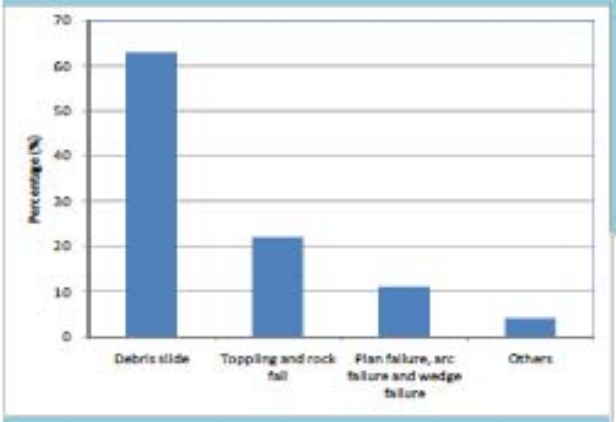
	Landslide			Dam break			Dam height(m)	Debris volume (m^3)	Dam capacity (m^3)	Block length (m)
	Date	Time	Factor	Date	Time	Factor				
(1)	1862	-	Earthquake	-	-	-	-	-	-	-
	-	-	-	1875	-	-	-	-	-	-
	-	-	-	1898	-	-	-	-	-	
(2)	1941.12.17	04:17 AM	Earthquake	-	-	-	200	15,000,000	120,000,000	2,000
	1942.08.10	12:00 PM	Rainfall	-	-	-		20,000,000		
	1942.08.10	12:10 PM	Rainfall	-	-	-				
	-	-	-	1951.05.18	-	Rain	-	-	-	-
(3)	1979.08.15	04:00 AM	Rainfall	-	-	-	90	5,000,000	40,000,000	2,000
	-	-	-	1979.08.24	11:30 AM	Rain	-	-	-	-
(4)	1999.09.21	01:47 AM	Earthquake	-	-	-	50	17,000,000	46,000,000	4,815

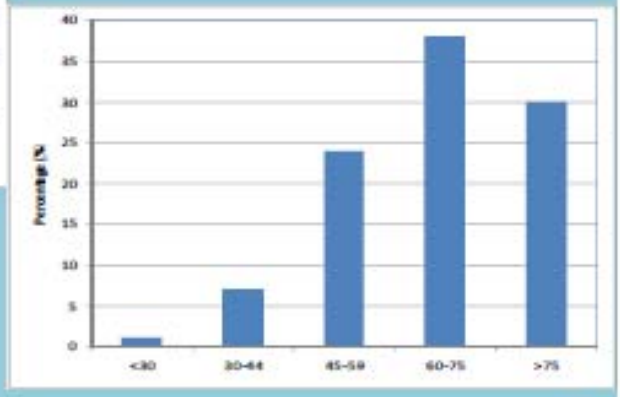
Wu et al.(2001)

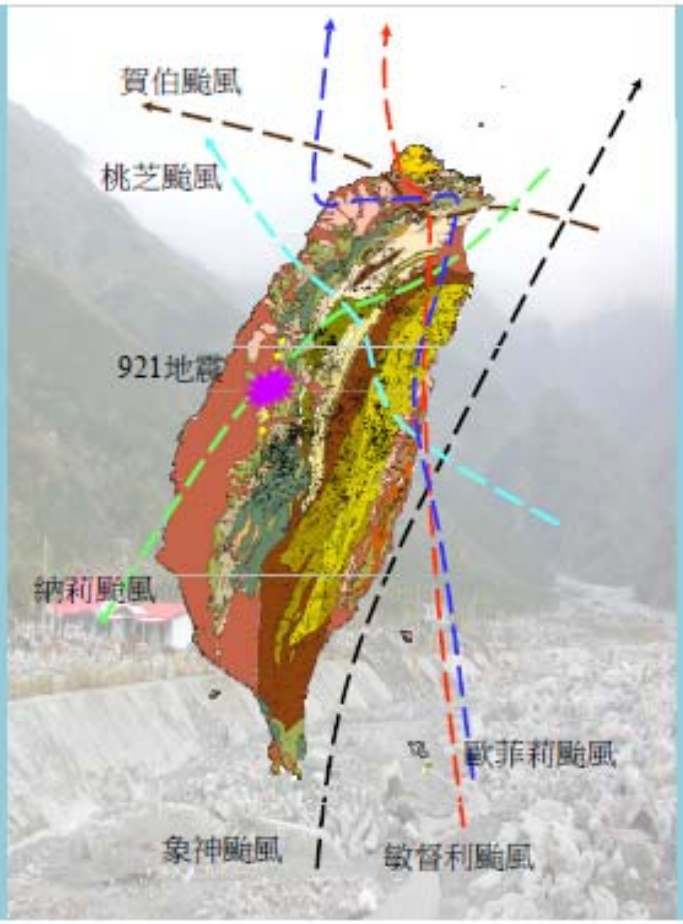


Influence Factors of Slope Failure

Characteristics of Slope Failures







Paths of typhoons causing significant hazard

Debris Flow Hazards in Taiwan

- In 1990, typhoon Ofelia induced Tung-man area debris flow with 39 people killed.
- In 1996, typhoon Herb induced debris flow in Nantou County, and 41 people were killed.
- In 2000, debris flow caused by Xiansane typhoon struck the northern Taiwan and killed 8 people.

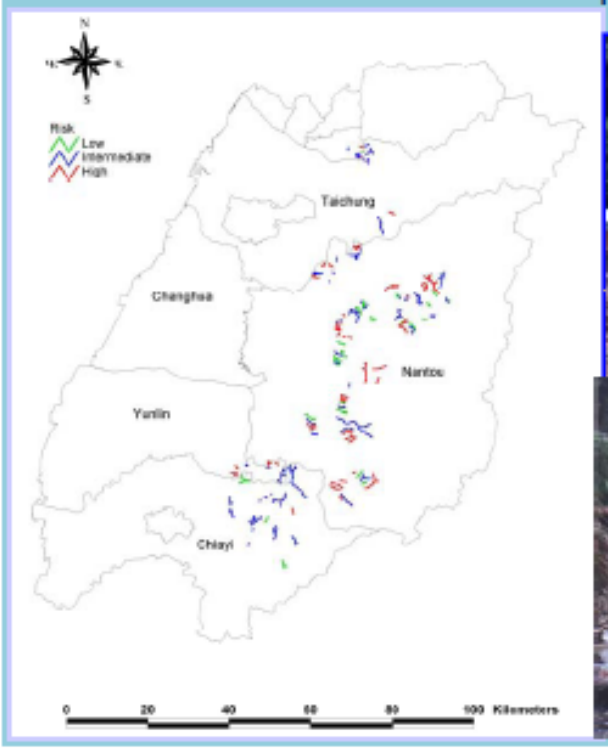
25

Previous debris flow hazard

date and items	1959, typhoon Ellen	1982, typhoon Sieth	1990, typhoon Ofelia	1996, typhoon Herb
location	Pa-gua mountain debris flow	Lin-kou tableland debris flow	Tung-man area debris flow	debris flow
No of death	1075	17	39	41
No of injury	295	7	10	65
Affected area	2	110He.	>10 He.	600He.
House destroyed	22426	36	24	--
House damaged	18002	51	11	--
Property loss (NT$)	>34 billions	10 billions	>10 billions	>100 billions
48hrs. max rainfall (mm)	1034	365	491	1987

26

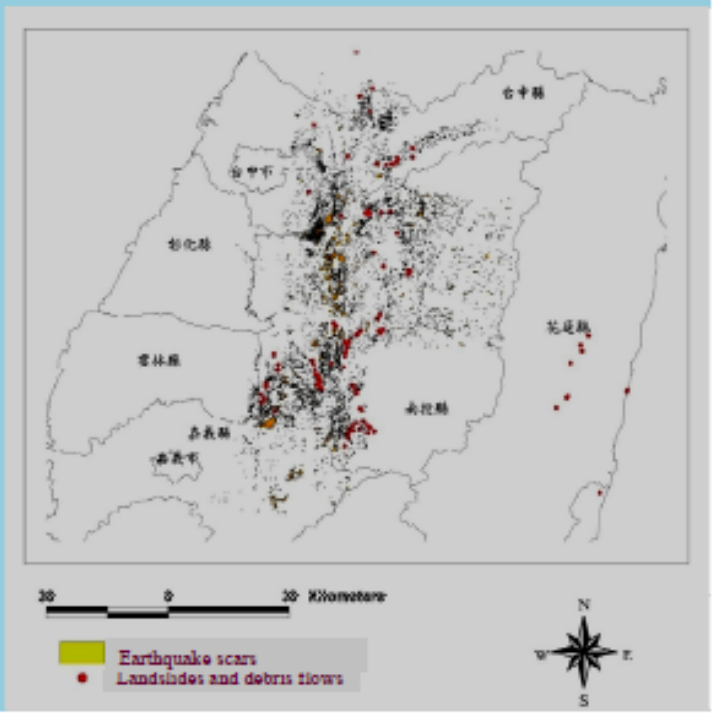
Distribution of the Potential Debris Flow Torrents in the Central Taiwan for Secondary Hazard after Chi-Chi Earthquake



Debris Flows Caused by Typhoon Toraji, 2001

Debris Flows Caused by Typhoon Toraji, 2001

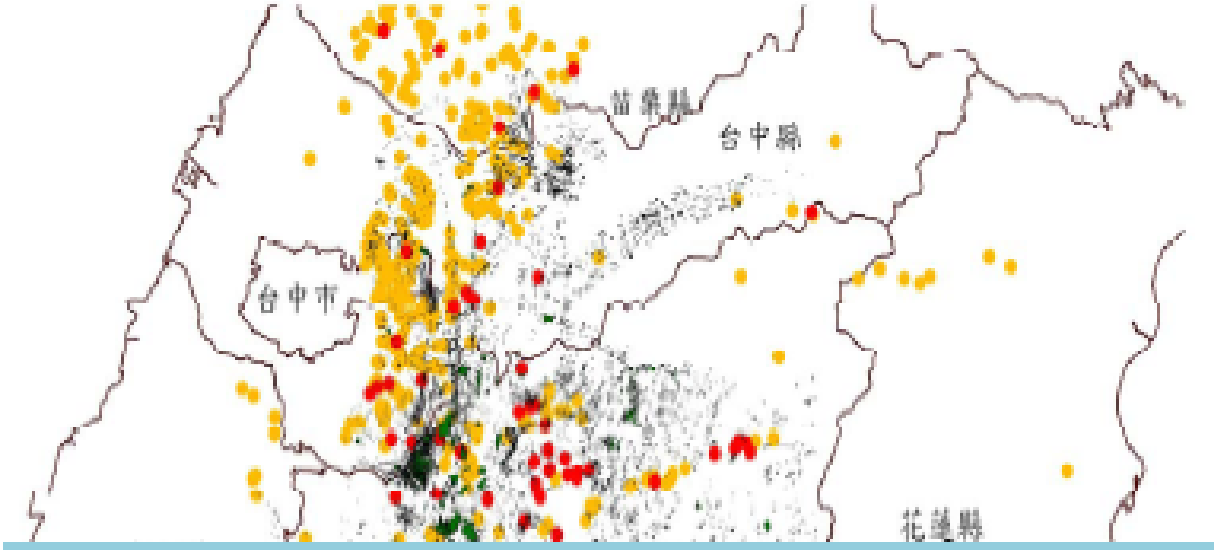
Landslides and Debris Flow Caused by Typhoon Toraji, 2001

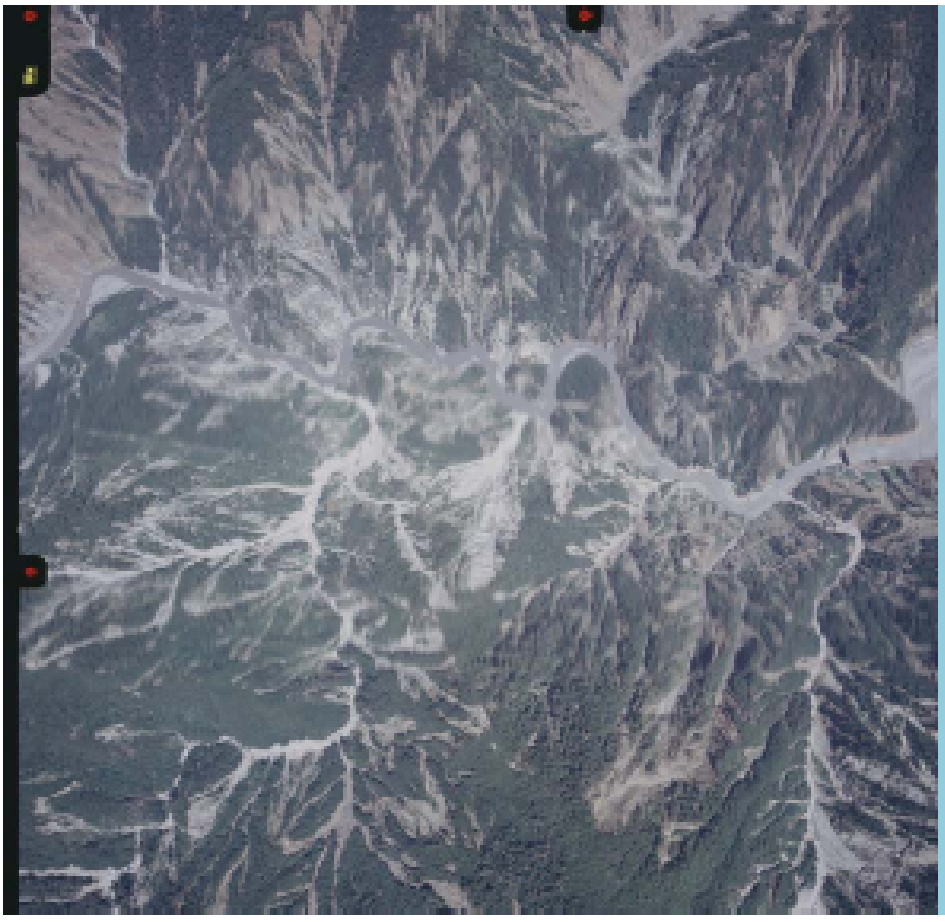


Min-du-li typhoon, july 2nd, 2004

Debris flow of Song-Her village

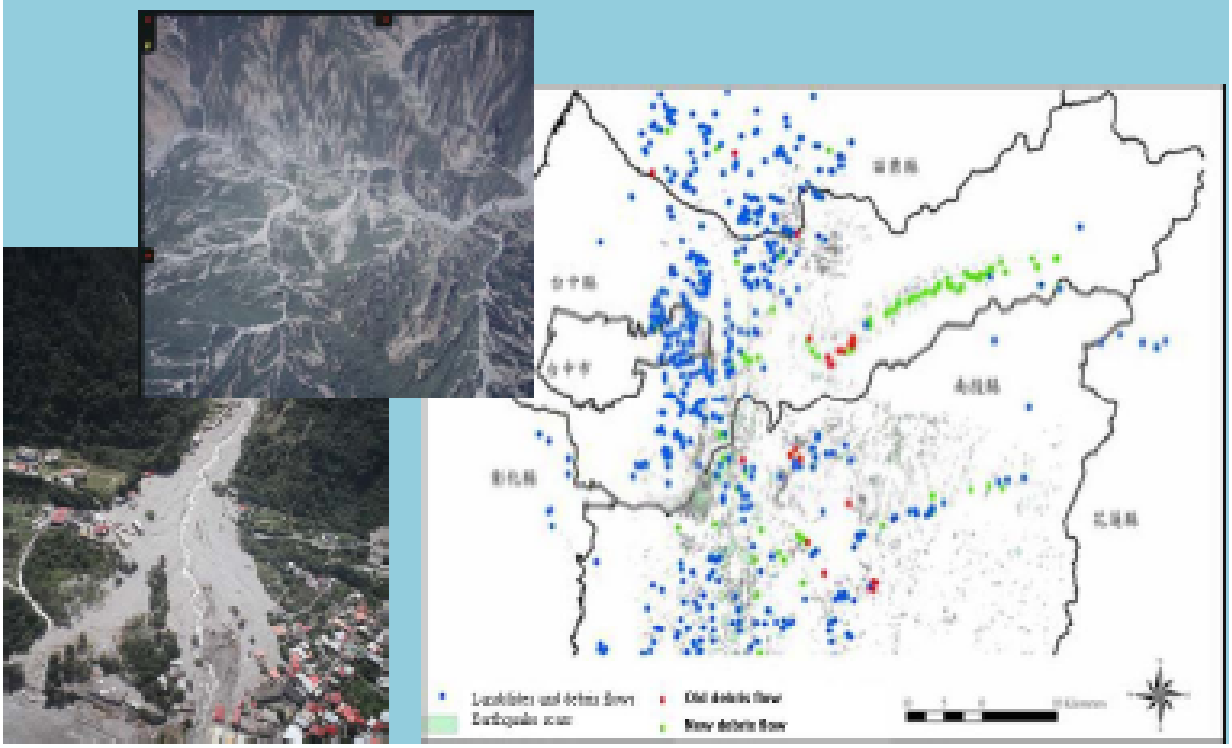
Effects of Earthquake on Subsequent Hazard





Aerial photo of central cross-island highway after Min-du-li Typhoon

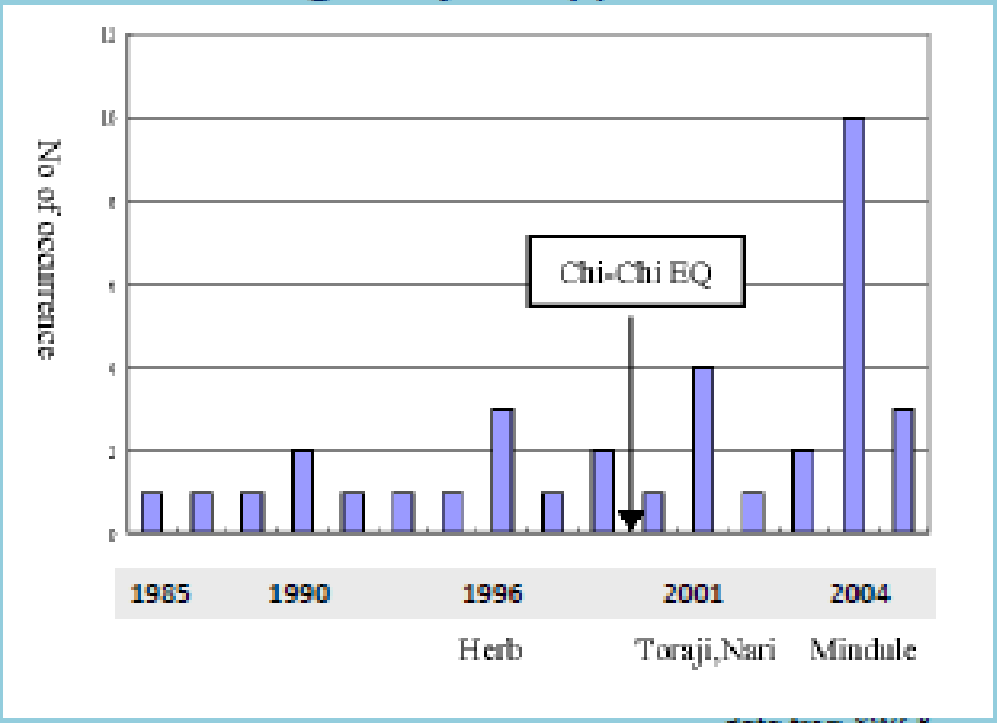
Landslides and Debris Flows Caused by Typhoon Mindule, 2004

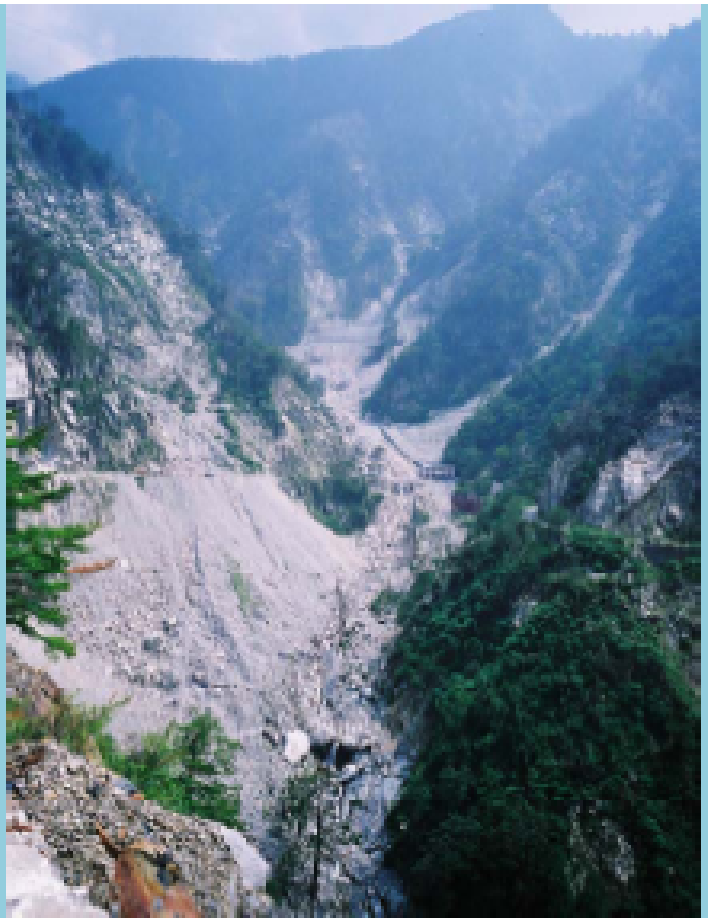


The Landslide Ratio of the Ta-Chia river Watershed and Chen-You-Lan River Watershed Triggered by three Major Events

Triggering event	Ta-Chia river watershed	Chen-You-Lan river watershed
Chi-Chi EQ	0.48%	2.46%
Toraji	1.63%	3.95%
Toraji & Chi-Chi	0.48%	2.16%
accumulated rainfall of typhoon Toraji, mm	480	634
Mindule	3.19%	4.83%
Mindule & Chi-Chi	0.94%	1.57%
accumulated rainfall of typhoon Mindule, mm	1658.5	1418

Recurring of 14 Debris Flow Torrents During Major Typhoon Events

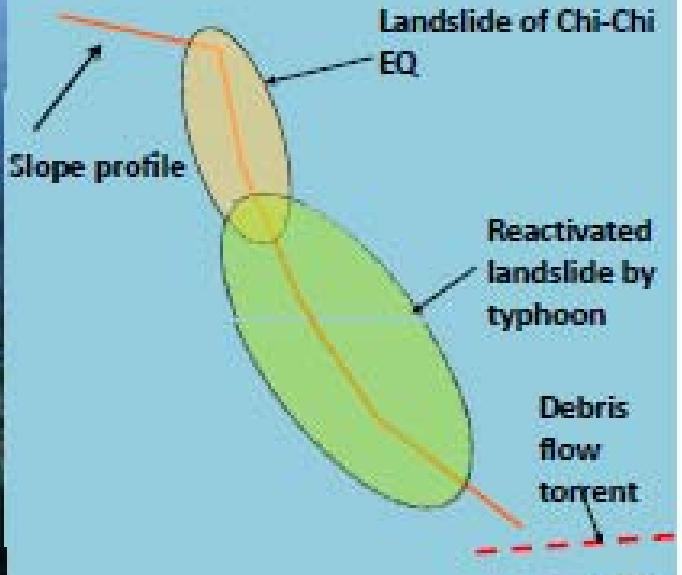




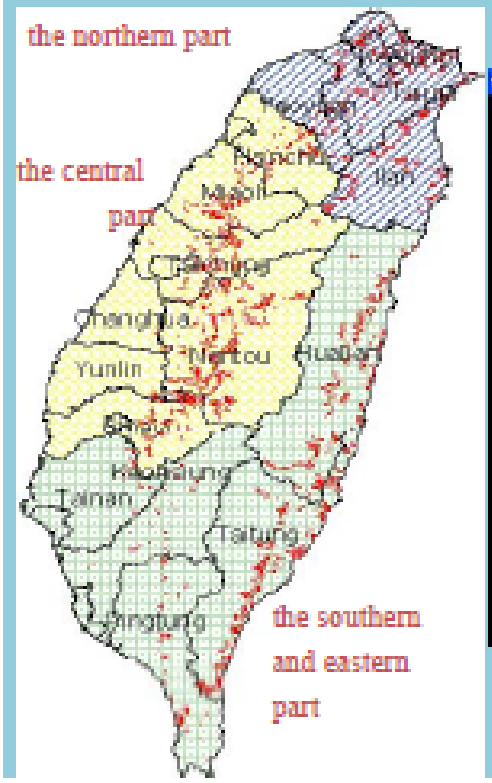
August , 2002
Central trans-island highway

Same section after Typhoon Min-du-li, July 10th, 2004

Reactivated Landslides and Triggering of Debris Flows Following Earthquake Induced Landslides



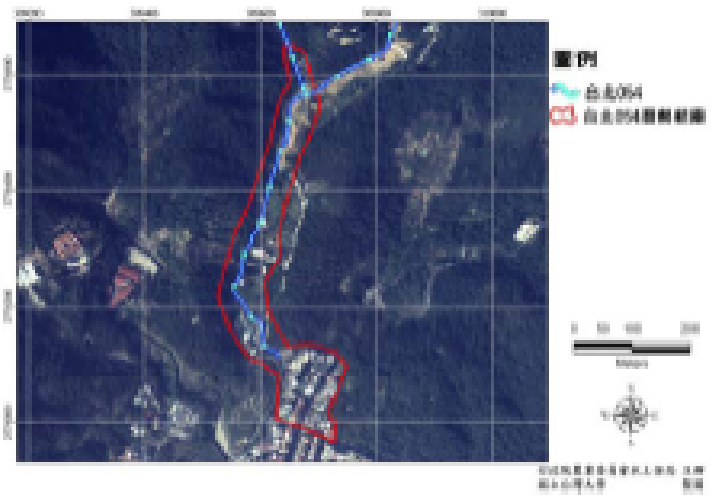
Potential Debris Flow Torrents Database



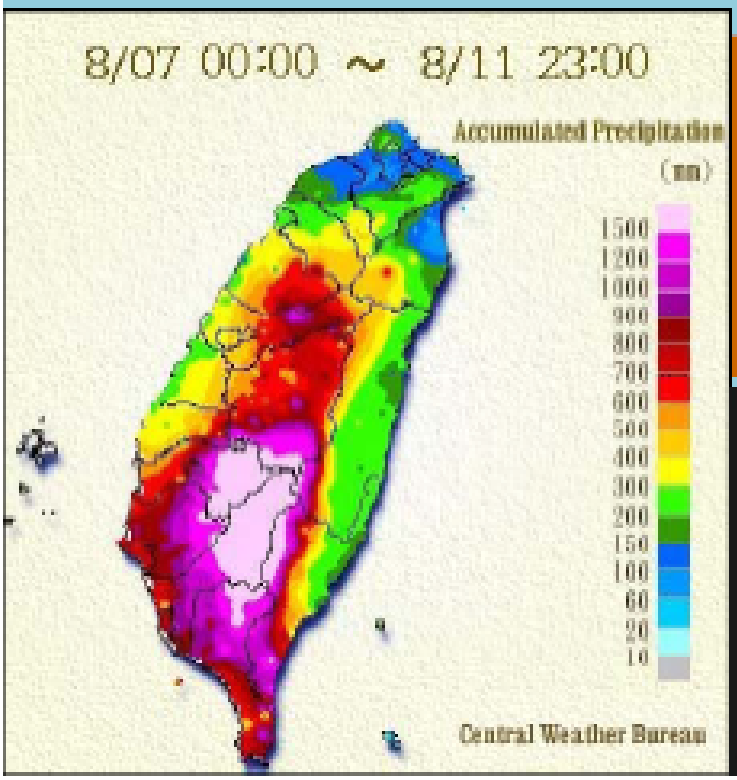
Distribution of number of potential torrents within different geological formations

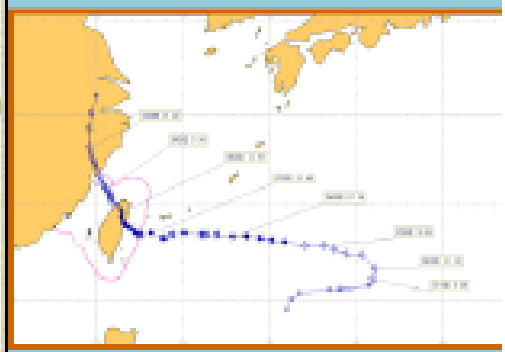
Type of formation	Area (10^3He.)	No. of torrents	No. of torrents per 10^3He.
A (Coastal Range)	248	190	0.77
B (Schist)	470	57	0.12
C (Slate)	1091	379	0.35
D (Sedimentary rock)	774	577	0.75
E (Laterite)	223	76	0.34
F (Igneous rock)	31	47	1.53
G (others)	789	94	0.12

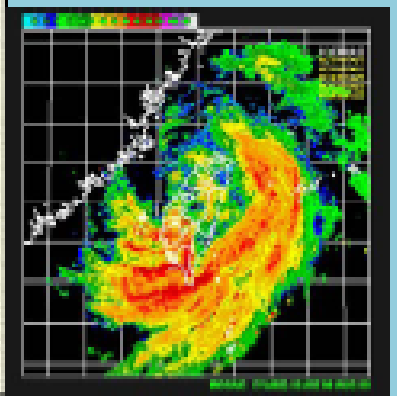
Debris Flow Database and Potential Map



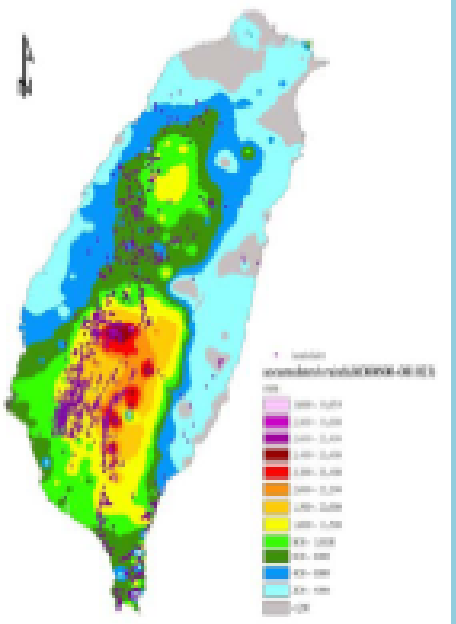
Typhoon Morakot, 2009



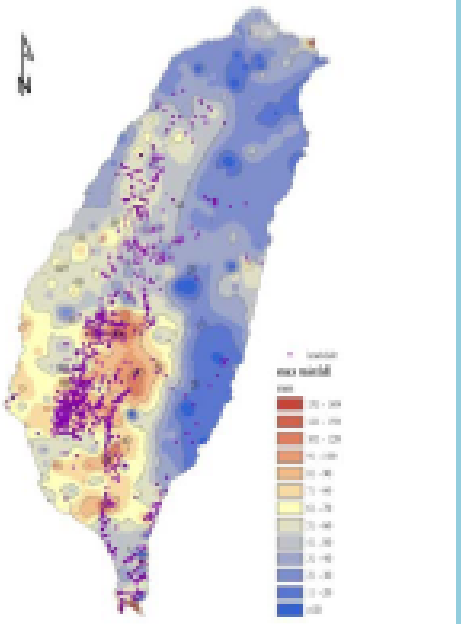




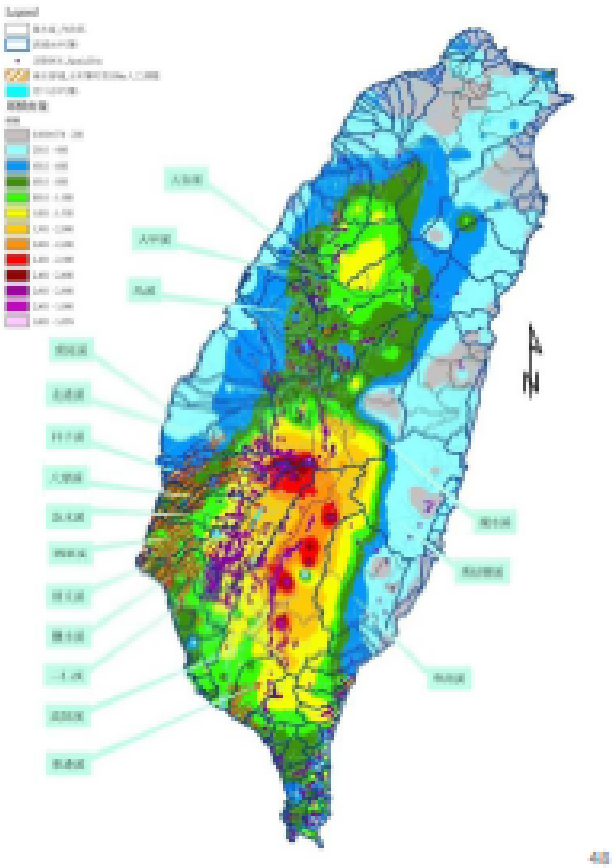
Distribution of accumulated rainfall and slope hazard



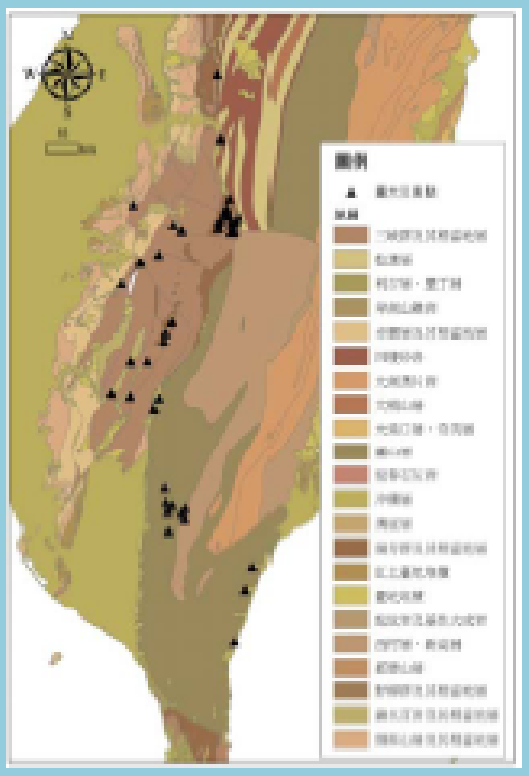
Distribution of maximum rainfall intensity and slope hazard



Accumulated rainfall versus landslide and flooding hazard



Geological formations and severe hazard

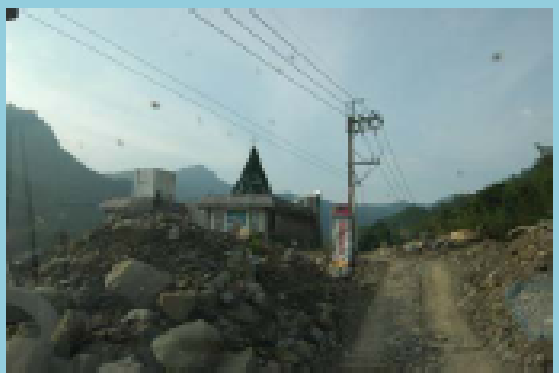


Highway20 in Chia-Sheng area

Nanshalu Village, Kaoshiung City

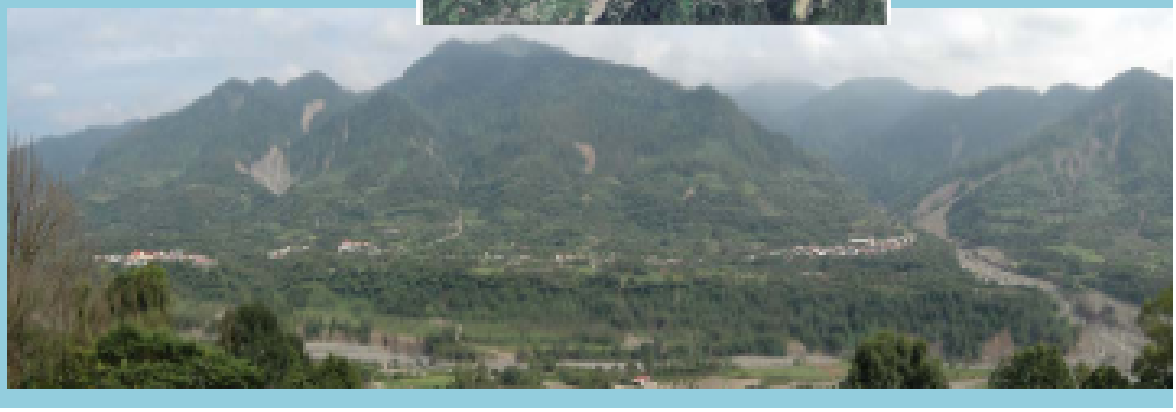
51

Maya Village, Kaoshiung County



52

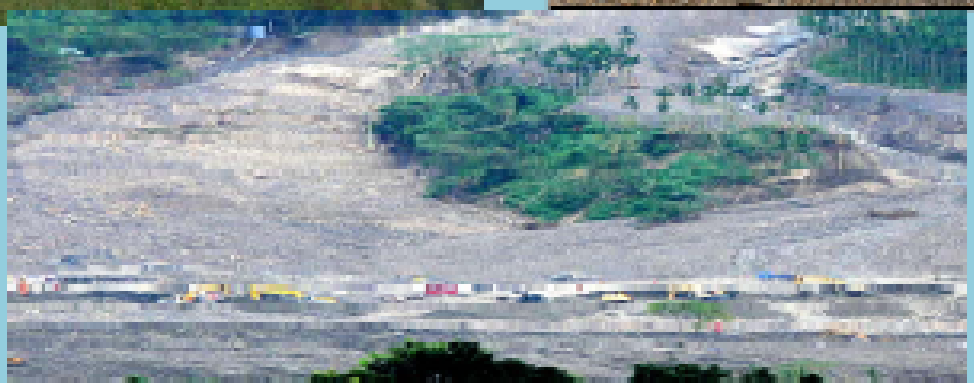
Dakanuwa village surrounded by debris flow

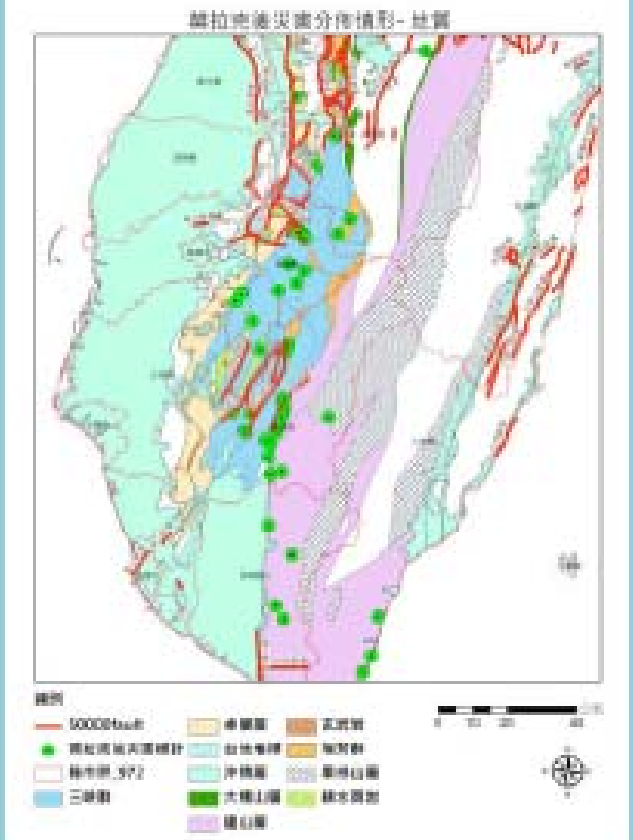


Shinkai Area, Kaoshiung City

By: TC Chen

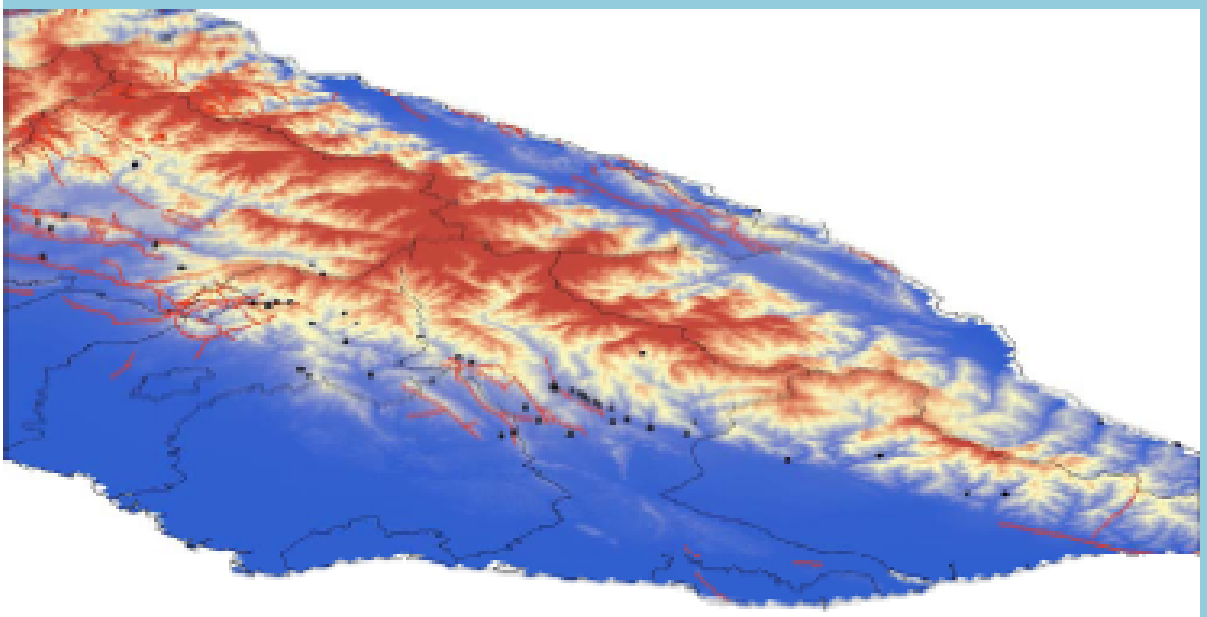
Shinkai Area, Kaoshiung City



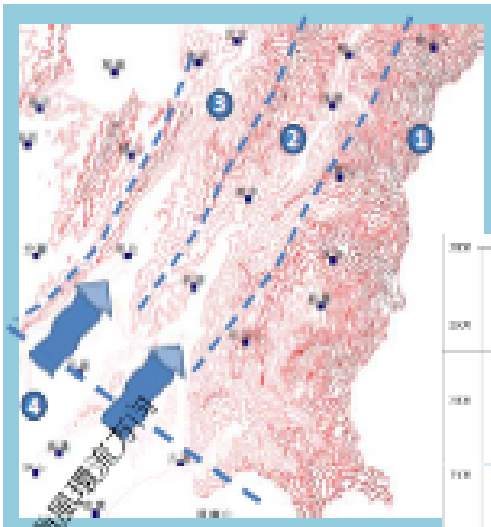


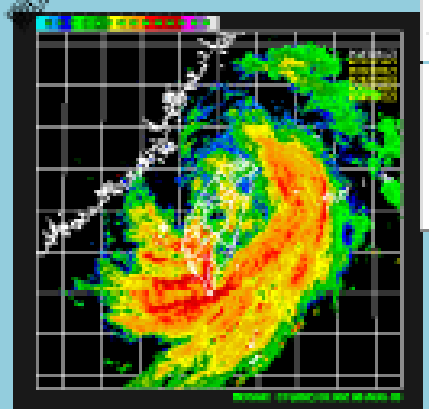
Geological formations and distribution of debris flow

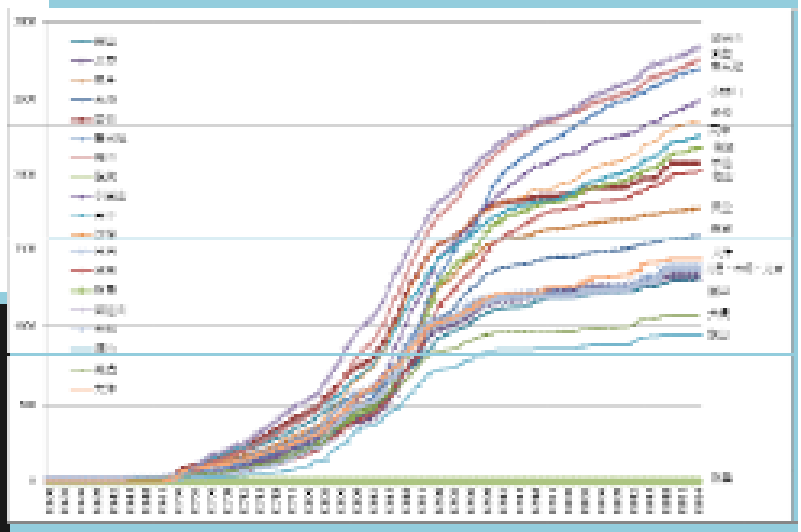
Distribution of debris flow versus faults



Alignment of river channels and current of weather system







County road 155, Alishan Township

Tou-kern stream debris flow

- River channel pushed away causing bank scouring
- Lung-hua elementary school
- Tai 21 highway

Lai-chi Village, Alishan Township

Mitigation Measures- emergency response

Typhoon Event	Maximum Intensity (mm/hr)	Total Accumulated Rainfall (mm)	Evacuation (Person)	Ceased and Missing (Person)
2001.07.28 Toraji	147	1757	----	214
2001.09.17 Nari	142	1,462	24,000	104 (enforcing evacuation)
2004.06.30 Mindulle	167	2,005	9,500	41 (delineation maps by 2003)
2005.07.18 Haitang	177	2,124	1,208	15
2005.09.01 Talim	119	766	1207	6
2005.10.02 LongWang	154	776	945	2
2006.07.12 Bilis	95	1,013	409	3
2007.08.16 Sepat	122	1,399	2,531	1
2008.07.16 Kalmaegi	161	1,027	179	26
2008.07.28 Fung-Wong	121	830	1,303	2
2008.09.10 Sinlaku	97	1,608	1,987	22
2008.09.27 Jangmi	85	1,137	3,361	4
2009.08.07 Morakot	100	2,965	24,775	695
2010.09.19 Fanapi	125	1,128	16,568	2
2010.10.22 Megi	182	1,196	3,453	38

Concluding remarks

- Due to the fragile geological conditions and steep terrain, Taiwan is prone to landslide hazard.
- The distribution of the landslide hazard is significantly affected by the geological settings and topography.
- Earthquakes and heavy rainfall are the two major triggering factors of the landslide hazard.
- The ground motion is the most important factor for causing landslides during earthquake, and the vertical peak ground acceleration has a significant effect.
- For a large magnitude earthquake, the landslide hazard is severe and leads to large affected areas and tremendous amount of debris yielding.

Concluding remarks

- With high intensity and prolonged precipitation, the landslide failures are severe and produce large volume of debris deposition.
- The secondary hazard is of major concern when a large-scale hazard occurs involving large landslide areas and huge amount of debris deposition.
- The emergency evacuation policy has been effective in reducing casualties, and database of potential landslide hazard and delineation maps are vital.
- Innovative mitigation policies are needed when dealing with the extreme hazard condition.

Thank you for your attention