Experimental Validation-Based Vulnerability Assessment and Mitigation Method Development for Mass-movement Disaster

2026. 2.

National Disaster Management Research Institute

Geotechnical Disaster
Experiment & Research Team Leader
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Mass-Movement Disaster Management Status

행정안전부
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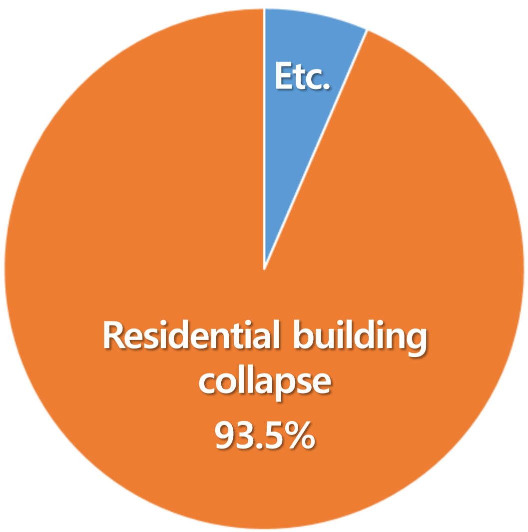
Current Status of Human Casualties('11~'23)

Natural Disaster Fatalities	Mass-Movement Disaster Fatalities	
535 people	108 people	→ 20%

Causes of Human Casualties from mass-movement disaster ('11~'23)



'12.8.15. Gong-ju city (1 fatality)

'17.7.16. Cheng-ju city (1 fatality)

'19.10.2. Ul-jin county (2 fatalities)

'20.8.3. Ga-pyeng county (3 fatalities)

Mass-Movement Disaster Management Status

Collapse Type and Damage Charcteristics of Building


< Wooden structures>


<Lightweight steel structures>

- Collapse of buildings due to concentrated impact on the lower structure (collapse area expands upward)
- Severe damage in management blind spots; difficult to predict
- Openings in RC-frame structures are vulnerable


< Masonry structures>

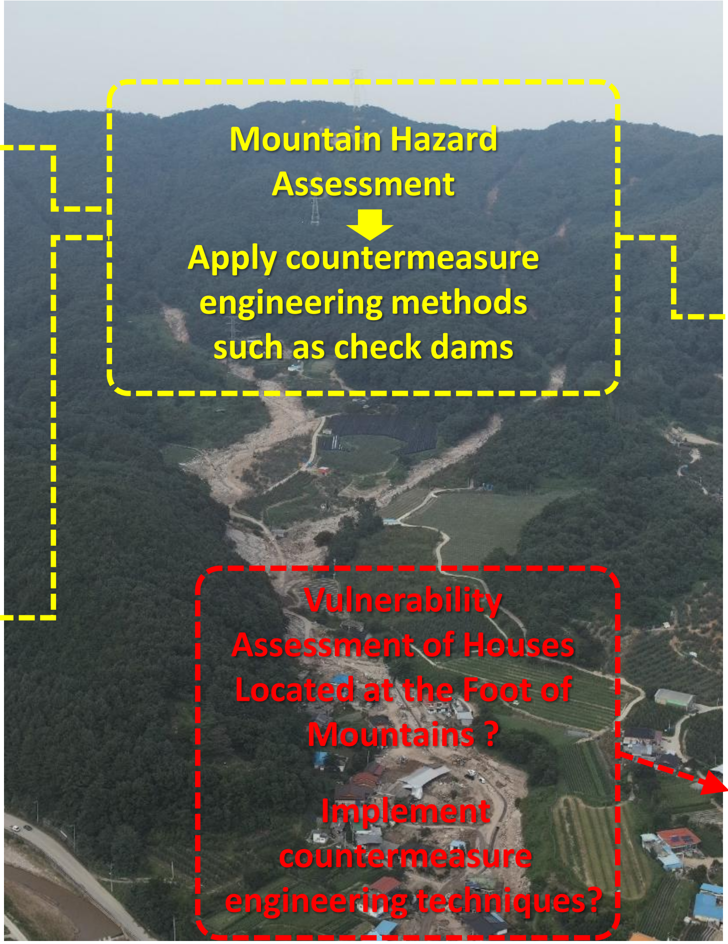

<RC structures>

Mass-Movement Disaster Management Status

The need for vulnerability assessment and Countermeasure methods against MMD

□ 현장조사 평가표(토석류) **Korea Forest Service**

인자			항목 및 점수 1	2	3	4	5	점수
피해 가능성 (15점)		피해이력	없음	간접피해	직접피해			
		점 수	0	3	5			
		직접영향권 내 보호시설	없음	경작지 등 재산피해	인가 1~4	인가 5 이상, SOC시설		
		점 수	0	5	7	10		
지형 (25점)		유역면적 (ha)	5 미만	5~10 미만	10~20 미만	20~30 미만	30 이상	
		점 수	1	2	3	4	5	
		계류 평균경사도(°)	5 미만	5~15 미만	15~20 미만	20 이상		
		점 수	3	5	8	10		
		토심 (cm)	30 미만	30~50 미만	50~80 미만	80~100 미만	100 이상	
		점 수	1	3	5	7	10	
위험 인자 (30점)	주 위험 요소 (20점)	구 분	하	중	상			
		붕괴	없음	높이 5m 미만	높이 5m 이상		주 위험요소 항목 중 높은 점수 택1	
			0	10	20			
		침식	5% 미만	5~20% 미만	20% 이상			
			0	10	20			
		전석	0%	10% 미만 또는 30% 초과	10~30%			
			0	10	20			
		토석류 흔적	무		유			
			0		10			
	잠재적 위험 요소 (10점)	산사태위험 등급현황	3등급 이하	2등급 50%미만	2등급 50%이상	1등급		
		점 수	0	1	2	3		
		산림현황	울페도(밀)	울페도 (소, 중)	수목전도 및 고사목	산림훼손지 황폐지		
		점 수	0	1	2	3		
		뿌리특성	심근성+천근성	심근성 (70% 이상)	천근성 (70% 이상)			
		점 수	0	1	2			
		기타위험요소 (선택형)	유송잡물, 퇴적지	용출수	유실	배수상태	기타위험요소 항목 중 택 1	
			2	2	2	2		
			단층대, 지진대		복합적 지질구조	기타(위험요소 기재)		
			2		2	2		
점수합계								



Ministry of the Interior and Safety & Local Government

[별표 2] 자연비탈면 및 산지의 재해위험도 평가표

구 분			평가기준 및 배점						점수
붕괴위험성 (70)	지형	경사각(°)	20 미만	20~33	34~43	44~53	54 이상		
			2	4	6	8	10		
		높 이(m)	25 미만	25~49	50~59	60~69	70 이상		
			1	2	3	4	5		
		급경사지 종단형상	철형	직선형	요형	복합형			
			1	2	3	4			
		자연비탈면 횡단형상	하강형	평행형	상승형	복합형			
			1	2	3	4			
	지반·지질	지반 변형·균열	없음	있음					
			0	5					
		토층심도(㎝)	0~20	21~50	51~70	71~90	91 이상		
			1	2	3	4	5		
		상부외력	무	전, 답, 묘지외	송전탑, 주택	철도	도로	임도	
			1	2	4	6	8	10	
		붕괴·유실이력	없음	낙석	10% 미만	10%~20%미만	20% 이상		
			0	2	4	6	8		
	시설	보호시설상태	양호	불량	매우 불량	무			
			0	2	4	5			
	강우	비탈면 계곡: 계곡 연장(m)	0~10	11~30	31~50	51 이상			
			1	2	3	4			
		비탈면 계곡: 계곡 폭(m)	3 이상	2~3	1~2	1 미만			
			1	2	3	4			
		지하수 상태	건조	습윤	표면수	용수			
			0	2	4	6			
	소 계								
사회적 영향도 (30)	주변환경		임야·공원 시설	택지·도로·철도 등					
			3	5					
	피해인구수/도로차로수·교통량	도로와 접한 급경사지: 도로차로수(편도)	도로 1차로 이하	도로 2차로	도로 3차로 이상				
			1	4	7				
		도로와 접한 급경사지: 교통량(대/일)	500 미만	500~5,000	5,001~20,000	20,001~35,000	35,001 이상		
			1	2	4	6	8		
		그외 기타 지역 급경사지: 피해예상 인구수	0	1~4명	5명 이상				
			0	10	15				
	급경사지와 인접 시설물과의 거리		시설물 없음	비탈면높이 2배 초과	비탈면높이 2배 이내	비탈면높이 이내	비탈면높이 1/2배 이내		
			0	1	4	7	10		
	소 계								

Mass-Movement Disaster Management Status

Assessment Tables Related to MMD in Korea

Category		Ministry of the Interior and Safety		Korea Forest Service (* : Only for Soil slope)							
		Disaster Risk Assessment Table (Mountain area)		Preliminary Survey Assessment Table (Landslide)		Preliminary Survey Assessment Table (Debris flow)		Field Invetigation Evaluation Table (Landslide)		Field Invetigation Evaluation Table (Debris flow)	
		Evaluation indicators	Score	Evaluation indicators	Score	Evaluation indicators	Score	Evaluation indicators	Score	Evaluation indicators	Score
Harzard	Topography	Slope angle	10	Slope length	10	Average channel gradient	10	Slope angle	7	Watershed Features	5
		Height	5								
		Longitudinal profie	4	Slope angle	20	Watershed area	20	Height	7	Average channel gradient	10
		Cross-sec. profile	4								
		Valley length	4	Shape of slope	10	Total channel length	10	Longitudinal profie*	4		
		Valley width	4								
	Geology & Soil properties	Soil depth	5	Bedrock type	10	–		Soil depth*	7	Soil depth	10
								Bedrock type	7		
		Ground deformation and crack	5					Discontinuity orientation	10		
								degree of weathering	5		
	Risk elements	External force	10	Risk factors (rock-fall etc.)	20	Erosion source	20	Crack conditions	4	Main risk factors	20
		Collapse history	8					Landslide hazard grades	5	Landslide hazard grades	3
		Condtion of protective facilities	5			Risk factors (boulder etc.)	20	Collapse sites*	10	Additional risk factors	2
								Collapse	5		
	Hydrological elements	Ground water	6	–		–		Water conditions	5	–	
		Effect of rainfall	+12								
	Vegetation	–		Forest type	10	–		Root characteristics*	5	Forest status	3
								Forest status*	5	Root characteristics	2
	numerical simulation	–				–		Slope stability analysis	30	Debris flow simulation results	30
Sub Totla		82 points		80 points		80 points		85 points		85 points	
Vulnerability	Protected targets status	Protected targets structure	20	Protected targets	20	Protected targets	20	Damage history	5	Damage history	5
		Seperation distance	10					Protective facilities in direct impact zone	10	Protective facilities in direct impact zone	10
		Estimated population at risk	+5								
Sub Totla		35 points		20 points		20 points		15 points		15 points	
Grand Total		100 (Max 117)		100 points		100 points		100 points		100 points	

- Enforcement Decree of the Act on Prevention of Disasters in Steep Slopes (Ministry of interior and safety)
  - "Disaster Risk Assessment Table" classifies areas into grades A–E
  - Grades D and E are designated and announced as "Collapse Risk Areas"
- Forest Protection Act (Korea forest service)
  - 'Preliminary Survey Assessment Table' + 'Field Investigation Evaluation Table'
  - Grades A–C: Grades A and B are submitted to the Designation Committee and designated as "Landslide Hazard Areas"

An Evaluation system focused on the inherent collapse risk and potential of mountain area, based primarily on factors such as topography, geology, soil condition, and other hazard elements

Need for Vulnerability Assessment under Assumed MMD

Mass-Movement Disaster Management Status

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Core Objective

Current assessments related to MMD conducted by the Ministry of the Interior and Safety and Korea Forest Service focus solely on **evaluating the hazard of steep slopes or mountainous areas by experts**. There is **no vulnerability-assessment framework for residential areas** where actual casualties occur.

Establish a **residence-centered vulnerability-assessment framework** that can be used by field practitioners **who are not experts**.

For prevention of large-scale, wide-area debris-flow damage, current practice relies on the Forest Service's slope-management-oriented anti-erosion works (e.g., construction of check dams).

When check dams are installed in areas designated as landslide-prone by the Korea Forest Service, the average construction cost is JPY 30,000,000 and the dredging/maintenance cost behind the dam is about JPY 1,000,000 per year.

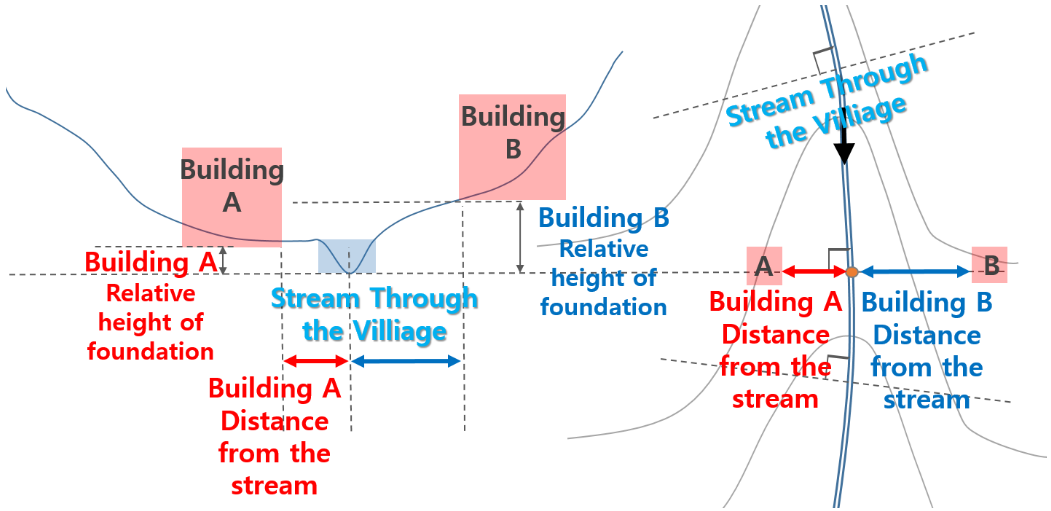
Develop residence-centered countermeasures for mass movement disaster reduction.

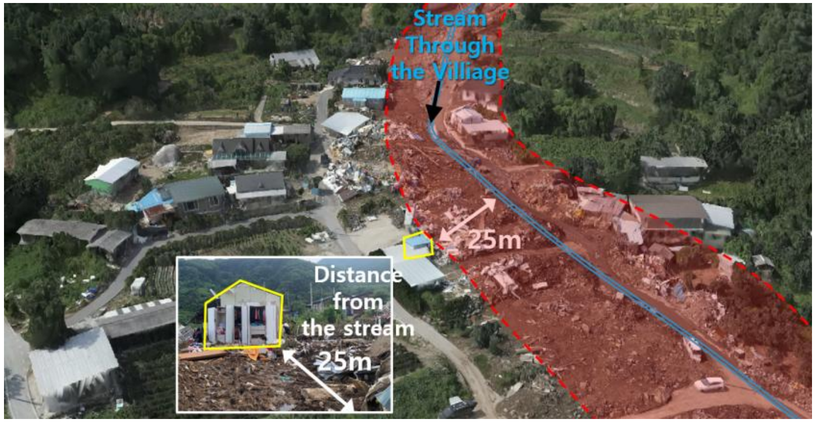
Develop economically feasible and simple construction mitigation methods that enable village-level debris-flow mitigation projects.

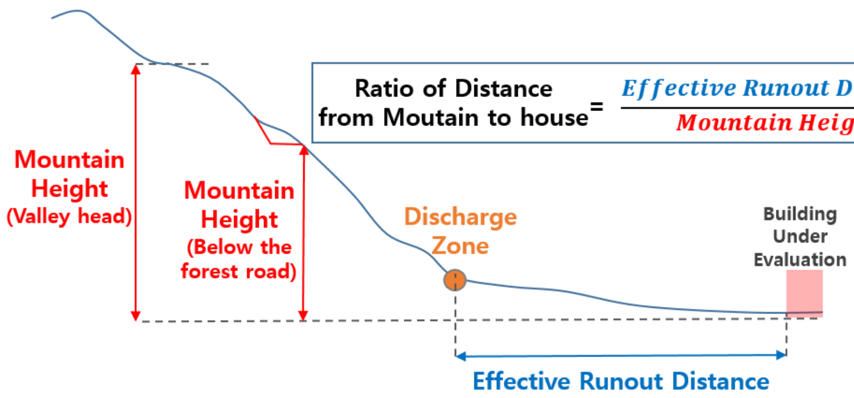
Develop semi-permanent mitigation methods that ensure long-term stability **without the need for frequent maintenance after a single installation**.

Development of a Vulnerability Assessment Table for Buildings Against MMD(Draft)('21~'23) – *Spatial Vulnerability Concept*

- Analysis of collapse ratio by section for 178 buildings located within risk zones of eight villages in Gyeongbuk Province affected by debris flow disasters in 2023





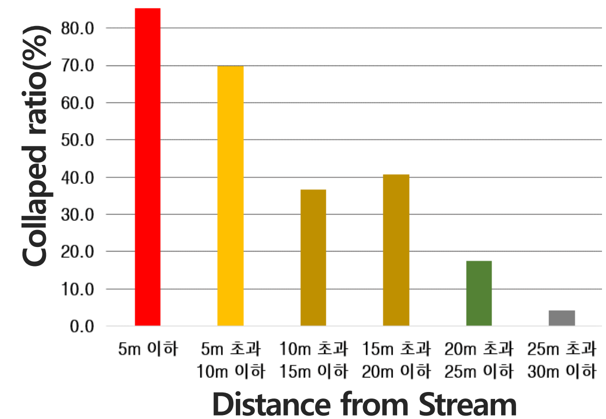


$$\text{Ratio of Distance from Moutain to house} = \frac{Effective\ Runout\ Distance(m)}{Mountain\ Height\ (m)}$$

Development of a Vulnerability Assessment Table for Buildings Against MMD(Draft)('21~'23)

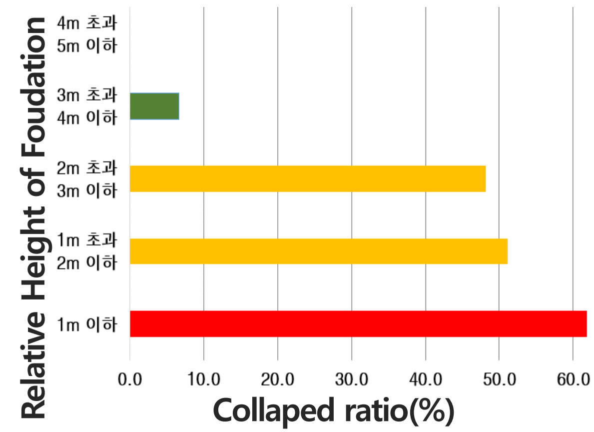
- Among the 85 buildings that collapsed due to structural damage (requiring reconstruction), Distance from the Stream was within 30 m — most within 25 m

Distance from Stream	< 5m	5~10m	10~15m	15~20m	20~25m	25~30m	Sum
No. of Bldg.	41	33	30	27	23	24	178
No. of Collaped	35	23	11	11	4	1	85
Collapse ratio	85.4%	69.7%	36.7%	40.7%	17.4%	4.2%	100%
	Collapse ratio for buildings within 25 m: 95.8%						



- Among the 85 buildings that collapsed due to structural damage (requiring reconstruction), Relative Height of Foundtion was within 4 m — most within 3 m

Relative Height of Foudation	< 1m	1~2m	2~3m	3~4m	Sum
No. of Bldg.	76	45	27	30	178
No. of Collaped	47	23	13	2	85
Collapse ratio	61.8%	51.1%	48.1%	6.7%	100%
	Collapse ratio for buildings within 3 m: 93.3%				



Vulnerability Assessment System for MMD

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Development of a Vulnerability Assessment Table for Buildings Against MMD(Draft)('24)

MMD(Debris flow) Vulnerability Assessment Key-indicators, Score & Grade

〈 Building vulnerability assessment table 〉

Key-indicators	Sub-indicators						Full marks
Distance from the stream	Masonry						45
	below 10m	over 10m under 20m	over 20m under 30m	over 30m under 45m	over 45m		
	45	20	5	1	0		
	Non-Masonry (Wooden, Panel house etc. / RC-frame is excluded)						38
	below 5m	over 5m under 10m	over 10m under 20m	over 20m under 25m	over 25m under 35m	over 35m	
	38	35	25	13	3	0	
Relative height of foundation	Masonry						26
	below 1.5m	over 1.5m under 2.5m	over 2.5m under 3.5m	over 3.5m under 4.5m	over 4.5m		
	26	14	7	3	0		
	Non-Masonry (Wooden, Panel house etc. / RC-frame is excluded)						55
	below 3m	over 3m under 5m	over 5m				
	55	11	0				
Ratio of distance from mountain to house	Masonry						13
	below 2.5	over 2.5 under 3.5	over 3.5 under 4.5	over 4.5			
	13	7	6	0			
	Non-Masonry (Wooden, Panel house etc. / RC-frame is excluded)						7
	below 1.5	over 1.5 under 2.5	over 2.5 under 4.5	over 4.5			
	7	6	4	0			
Maintenance status of house*	Masonry						10
	Bad	Moderate	Good				
	10	5	1				
Roof material*	Masonry						6
	etc(tile, slate, panel etc)	Concrete					
	6	1					
Total Score (out of 100)**							100

* Two key-indicators(Maintenance status of house & Roof materials) are used only in visual evaluation of masonry. Maintenance status of house is assessed based on the number of years of use when visual assessment is difficult.(below 10years: Good, 11~29years: Moderate, over 30years: Bad)

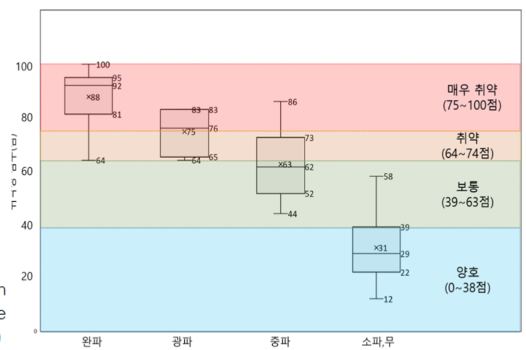
** Masonry and non-masonry buildings are each evaluated with a full score of 100

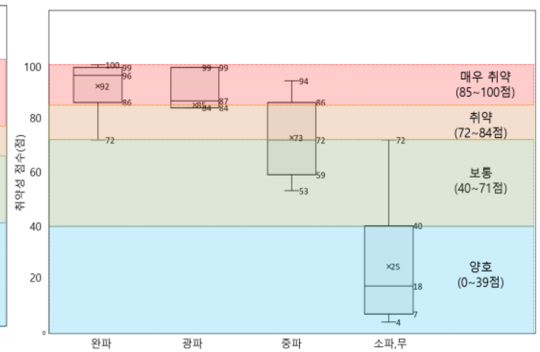
<Masonry building vulnerability assessment grade>

Buidling material	Grade by vulnerability assessment score			
Masonry	75~100 point	64~74 point	39~63 point	0~38 point
	Very vulnerable	Vulnerable	Moderate	Good

<Non-masonry building vulnerability assessment grade>

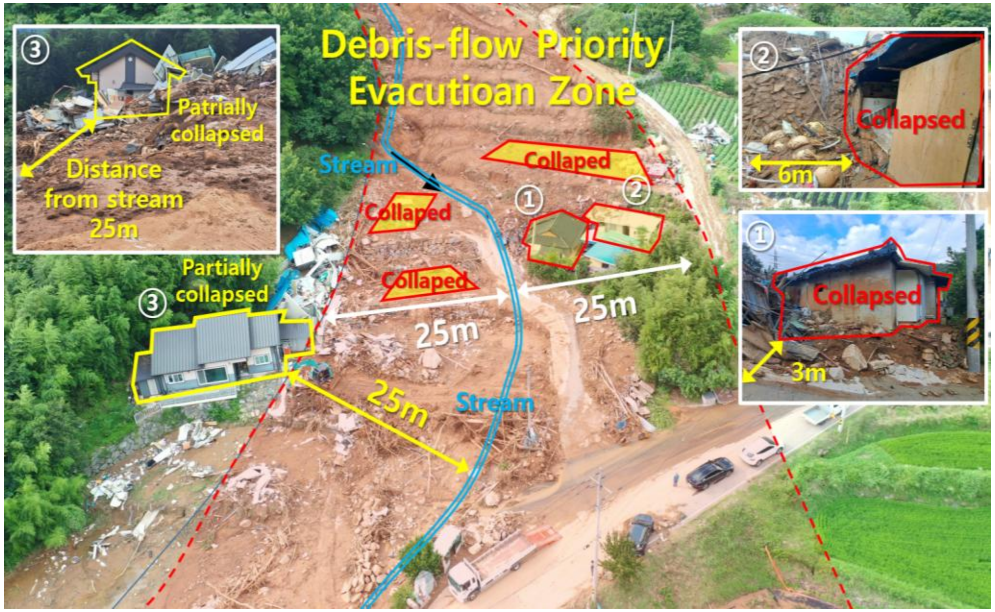
Buidling material	Grade by vulnerability assessment score			
Non-Masonry (Wooden, Panel house etc.)	85~100 point	72~84 point	40~71 point	0~39 point
	Very vulnerable	Vulnerable	Moderate	Good





Priority Evacuation Zones for Debris Flows

- Define the area with **Distance from the stream ≤ 25 m** as a **"Debris-flow Priority Evacuation Zone."**
  - ☑ Once a "Debris-flow Priority Evacuation Zone" is designated, residents within that zone should be prioritized for evacuation when rainfall exceeds a specified threshold (a conservative approach).
- **Enact new legal frameworks on debris-flow mitigation** to provide institutional management for residences located in "Debris-flow Priority Evacuation Zones."
  - ☑ Provide village-level budget support for structural measures (installation of debris-flow mitigation structures) and introduce non-structural measures (e.g., requiring mitigation systems during new construction).
  - ☑ In Japan, under the Sediment Disaster Prevention Act by the Ministry of Land, Infrastructure, Transport and Tourism, "Special Sediment Disaster Hazard Zones" are designated, which entail building regulations (e.g., structural strength requirements) and mandatory evacuation planning and drills.



Vulnerability Experiment on MMD

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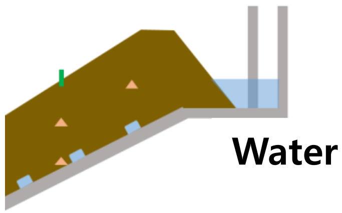
NDMI Experimental Simulator

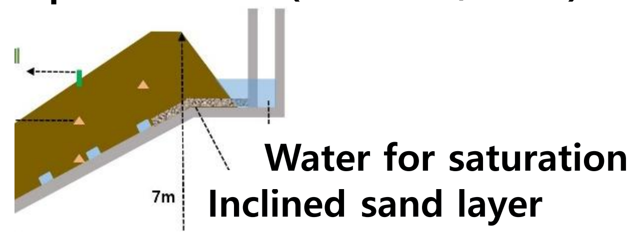
- Test bed dimensions: Height 6~10 m × Length 25 m × Width 4 m → capable of loading and inducing collapse of approximately 200 tons of soil (when saturated).
- The slope angle is adjustable within a range of 15°–40°, and the artificial rainfall system can reproduce rainfall intensities of 10–250 mm/hr.

Vulnerability Experiment on MMD

Implementing Realistic Landslide Velocity for MMD Assessment

⇒ Satisfied the range (4–5 m/s) known to cause building damage in prior studies (Cui et al., 2005)





Before improvement('21):
Inclined sand layer not applied
⇒ Collapse Velocity 1m/s

After improvement('23):
Inclined sand layer applied
⇒ Collapse Velocity 4~5m/s

Vulnerability Experiment on MMD

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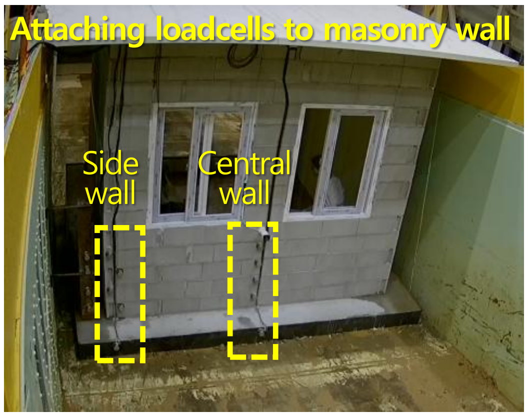
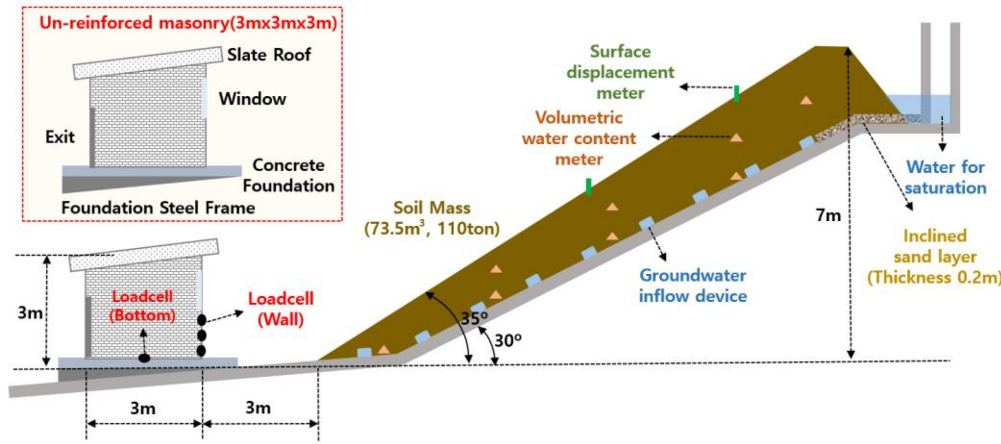
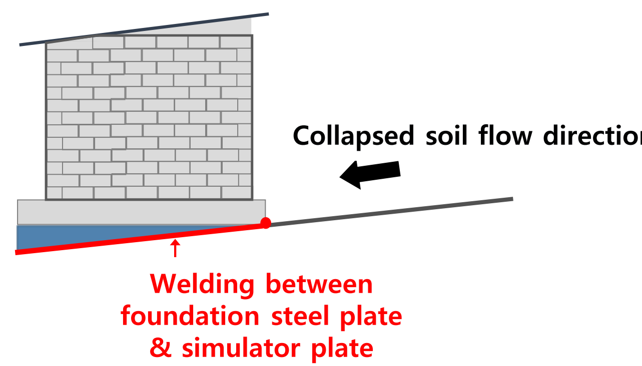
Vulnerability Test for Masonry Buildings

- Installed a steel frame with a concrete foundation, Inclined sand layer
- Load cells were installed on central and side walls, as well as on the indoor floor center







Vulnerability Experiment on MMD

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Vulnerability Test for Masonry Buildings

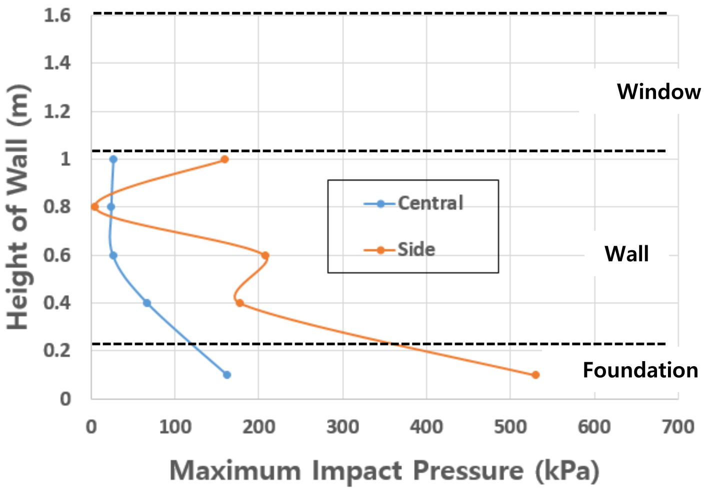
- Collapse sequence : Centeral wall → side walls → ceiling (collapsing inward)


Contacting foudation


Centeral wall collapsed


Side wall collapsed


Ceiling collapsed



- In the centeral wall with a height greater than 0.5m, the impact aborption capacity of the member was significantrly reduced.
- An impact mitigation effect was developed on the side wall as a result of the reaction forece.
- The entire masonry structure collapsed, the resident's safety could not be secured.
- The weight of collapsed bricks and soil generated an impact about two times greater(about 400kPa) than the lateral impact, causing severe harm to occupants.

Vulnerability Experiment on MMD

Vulnerability Test for Masonry Buildings

Experimental test of MMD Mitigation Method

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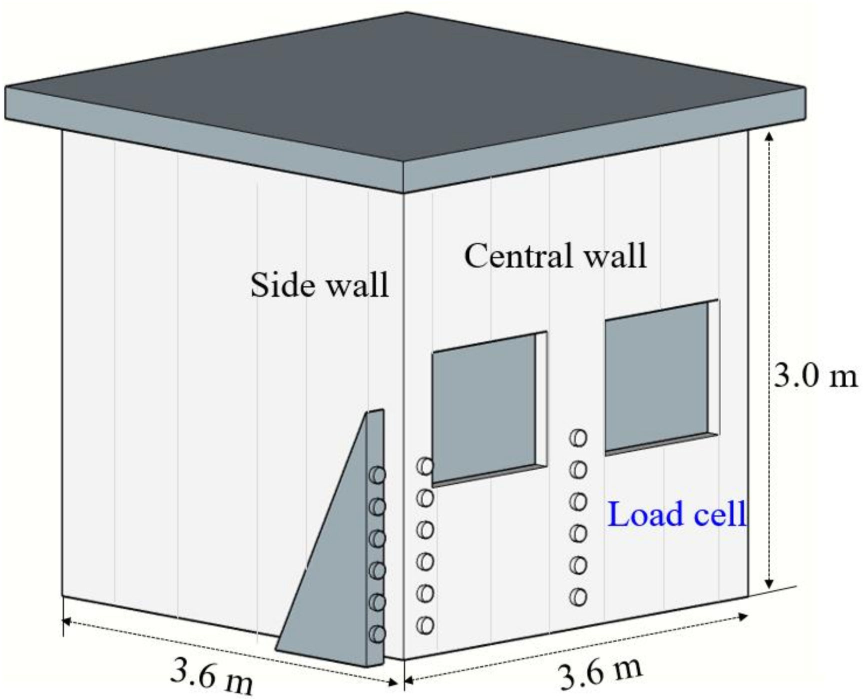
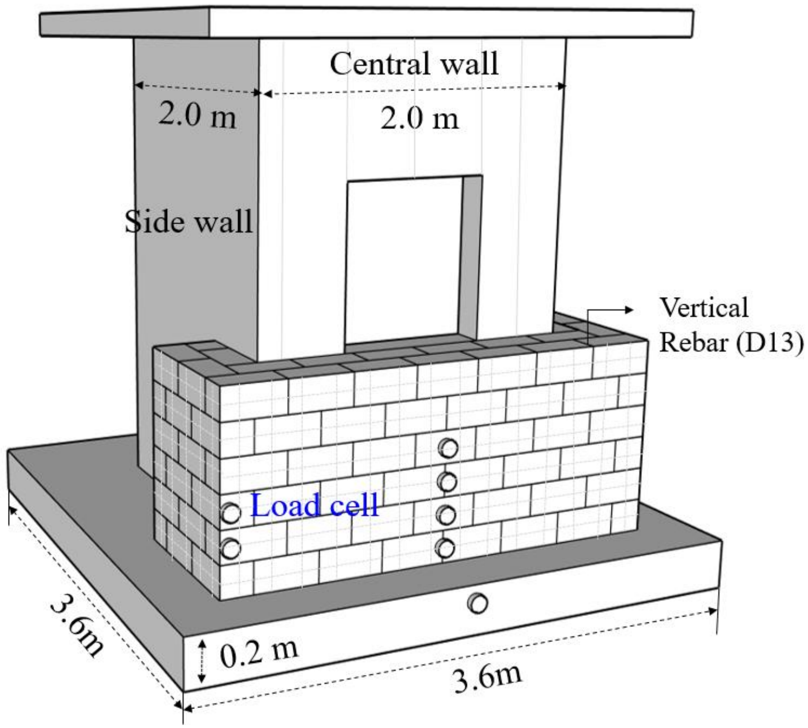
Full-Scale Reinforced Building

Unreinforced Panel Structures



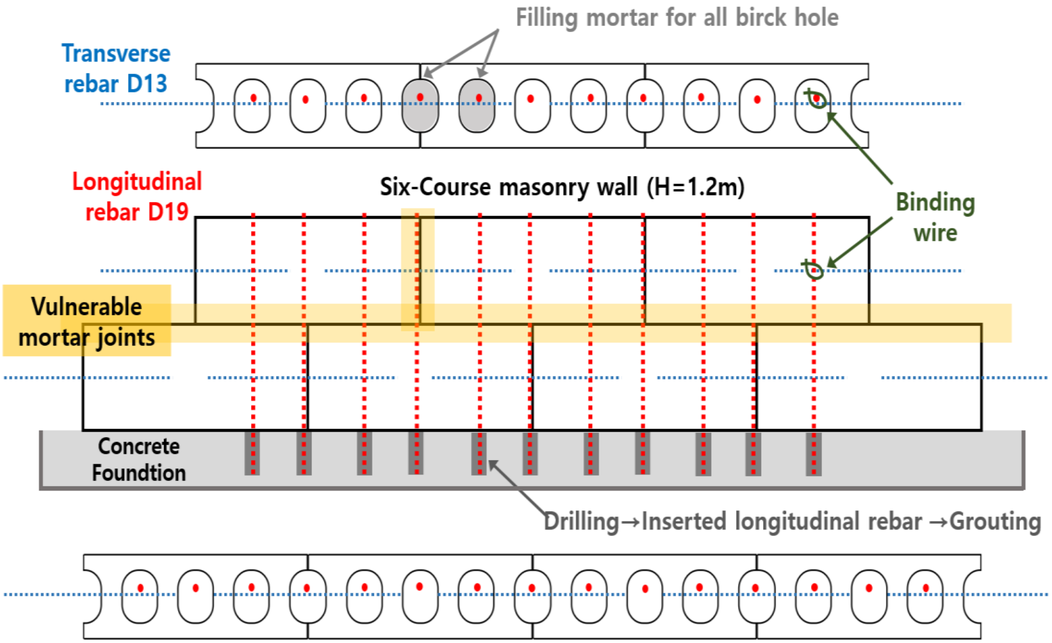
Reinforced masonry attachment method to Panel Structure



Design and development of structural defense methods based on experiments

Effectiveness Verification Experiment

- For vulnerable panel-type buildings, applied a "reinforced masonry attachment method (structural reinforcement)" + "window shutter installation (protective measure)"
  - ☑ Economic feasibility: Approx. 250,000 JPY for installation of 1.2 m height × 10 m length wall
  - ☑ Constructability: Can be installed in mountainous areas where ready-mix trucks cannot enter



Inserted longitudinal reinforcement into the foundation

Assembled longitudinal and transverse rebar aligned with brick holes

Injected mortar into the brick voids

Experimental test of MMD Mitigation Method

Effectiveness Verification Experiment

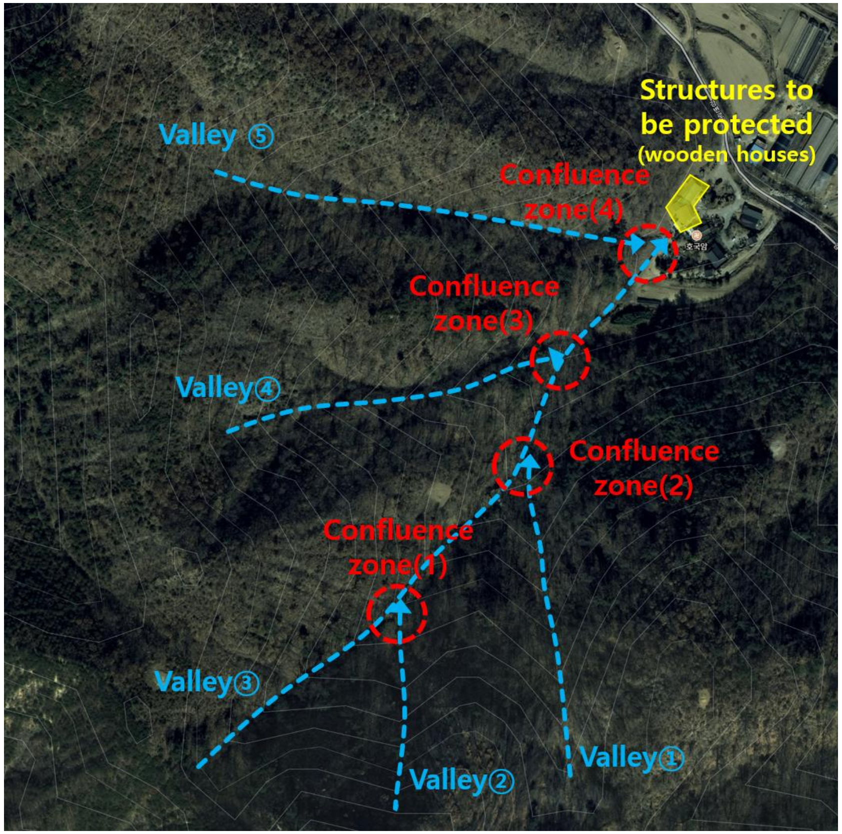
- ☑ Panel buildings reinforced with masonry attachment showed only minor damage
- ☑ No soil inflow observed in sections protected by window shutters

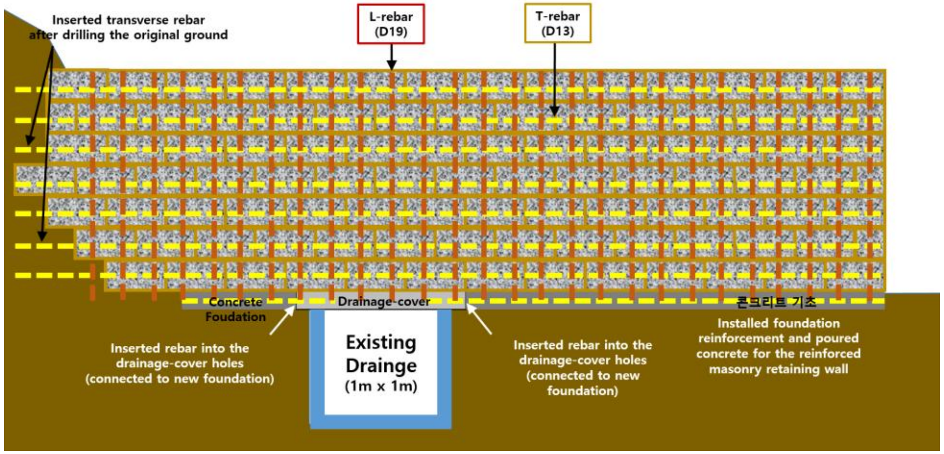
Field Application of MMD Mitigation Method

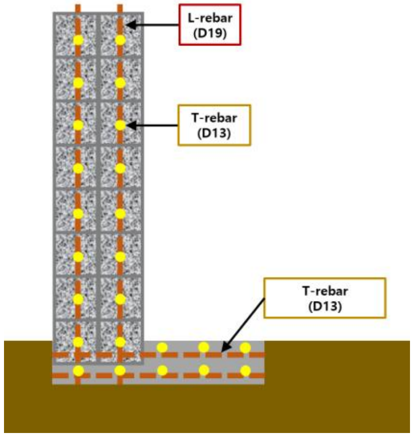
Reinforced masonry retaing wall

- Installed reinforced retaining walls (masonry blocks + longitudinal/transverse rebar + mortar) in front of wooden houses located in predicted debris-flow zones

Vulnerability: 100 Score(Very vulnerable grade)







Field Application of MMD Mitigation Method

Reinforced masonry retaing wall

- Installed reinforced retaining walls (masonry blocks + longitudinal/transverse rebar + mortar) in front of wooden houses located in predicted debris-flow zones



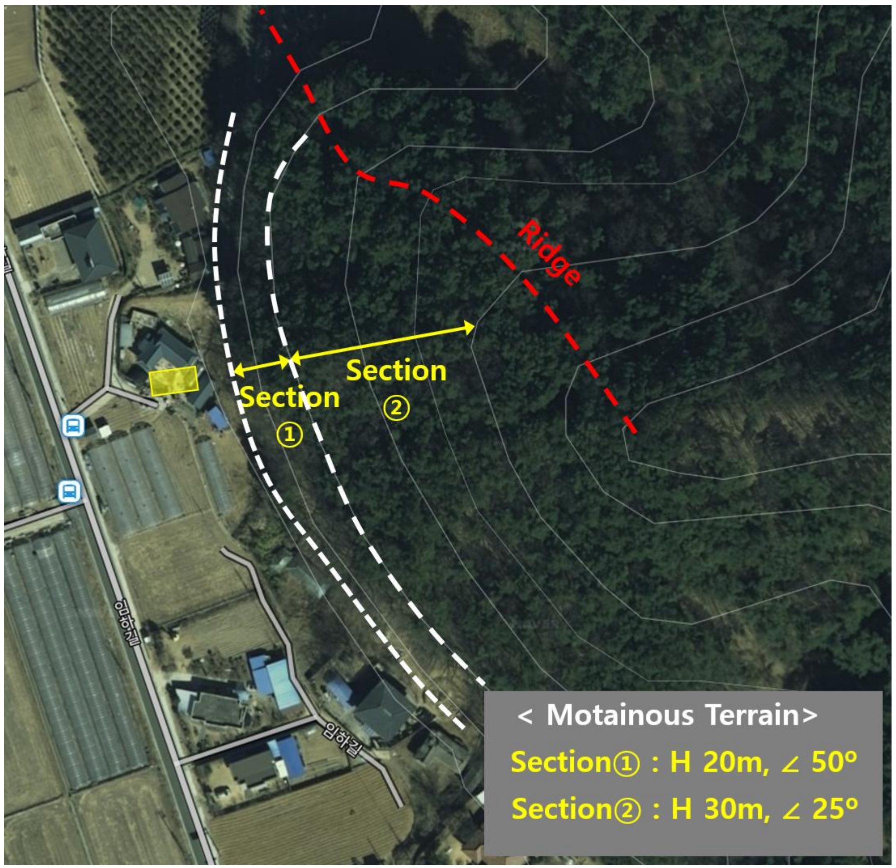


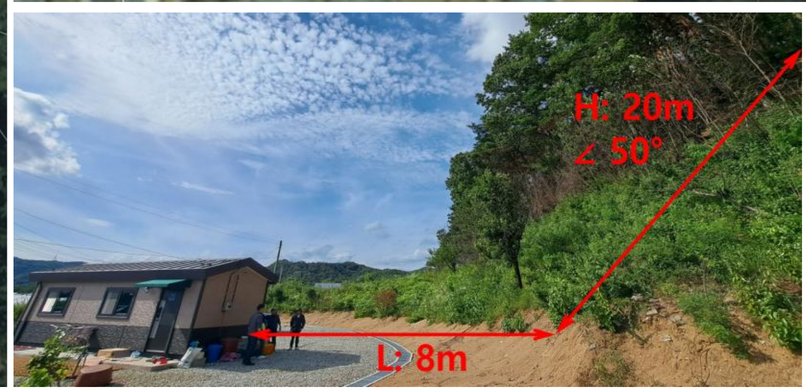

Field Application of MMD Mitigation Method

행정안전부
국립재난안전연구원

Reinforced masonry attached wall(Steep Slope in Wildfire-affected area)

- Temporary residential structures (light steel frames) located 8 m from the mountain boundary (approx. 0.4 H of slope height) — highly vulnerable)



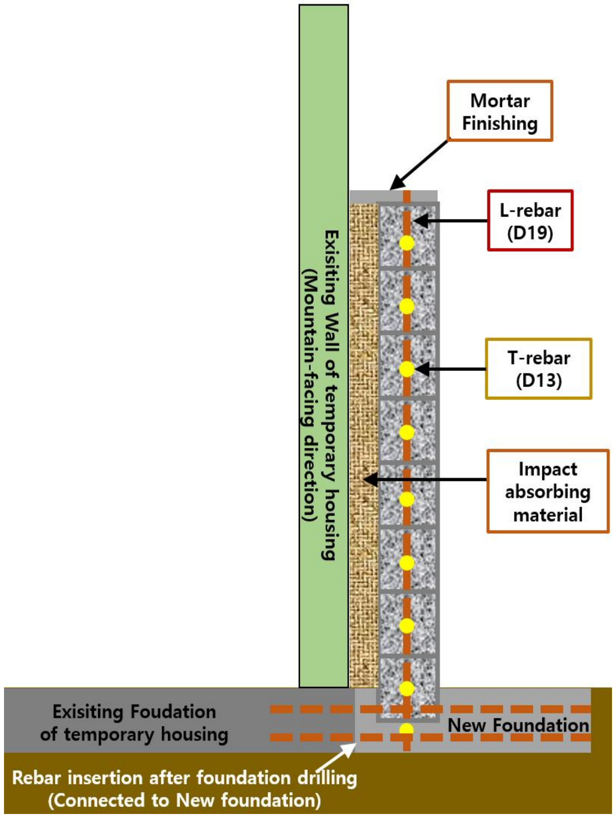


Field Application of MMD Mitigation Method

행정안전부
국립재난안전연구원

Reinforced masonry attached wall(Steep Slope in Wildfire-affected area)

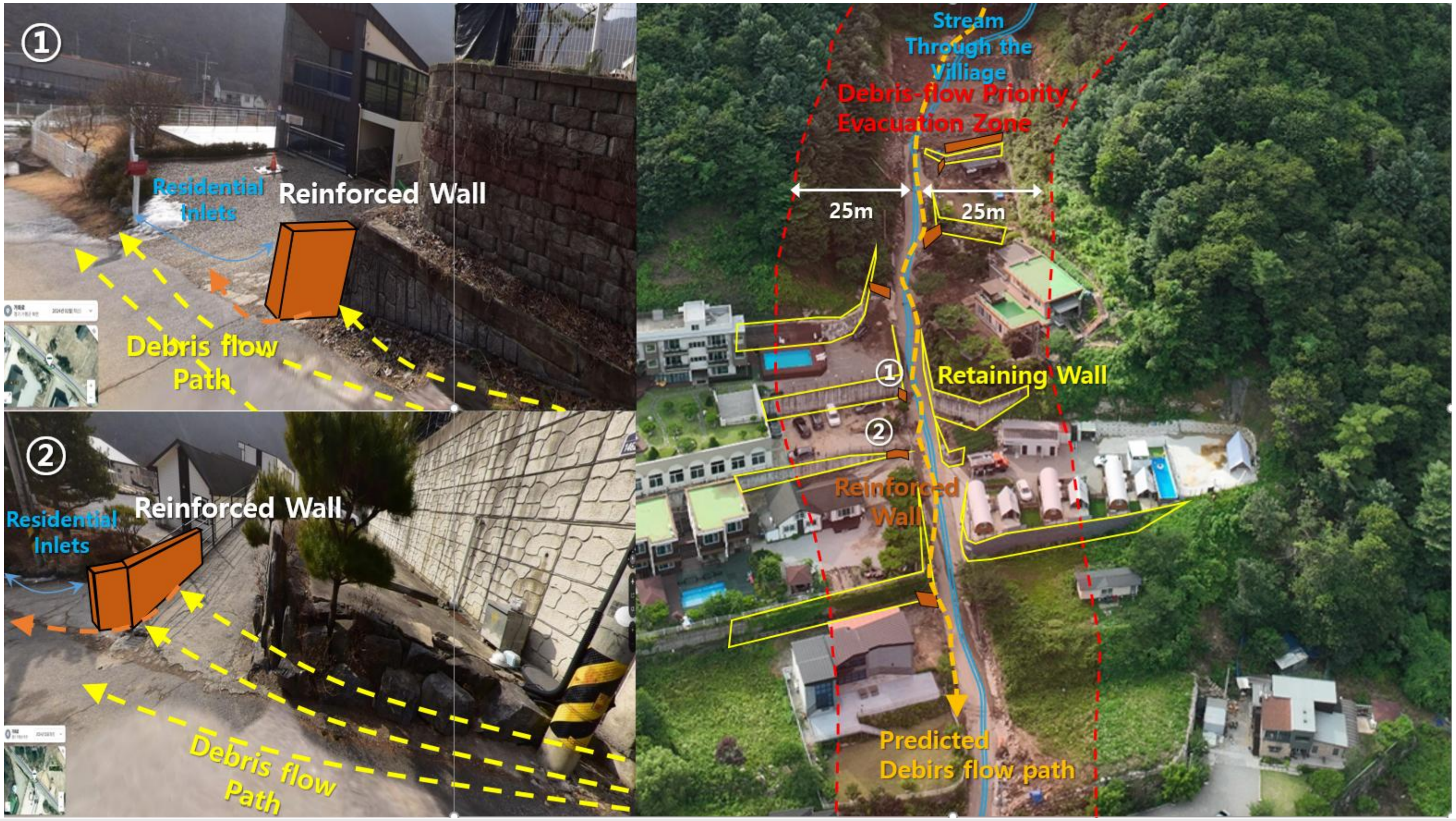
- On the mountain-facing wall of the temporary housing, applied "masonry blocks + longitudinal/transverse rebar + mortar + impact-absorbing material."



Field Application of MMD Mitigation Method

Example: Installation of Reinforced Masonry Walls (Village-Level Projects)

- In terraced terrain villages, houses are exposed to sediment inflow and possible overflow damage
- Reinforced masonry walls were installed near residential inlets adjacent to village stream(roads)
  → Debris flow can be guided through controlled pathways

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Thank you!
National Disaster Management
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