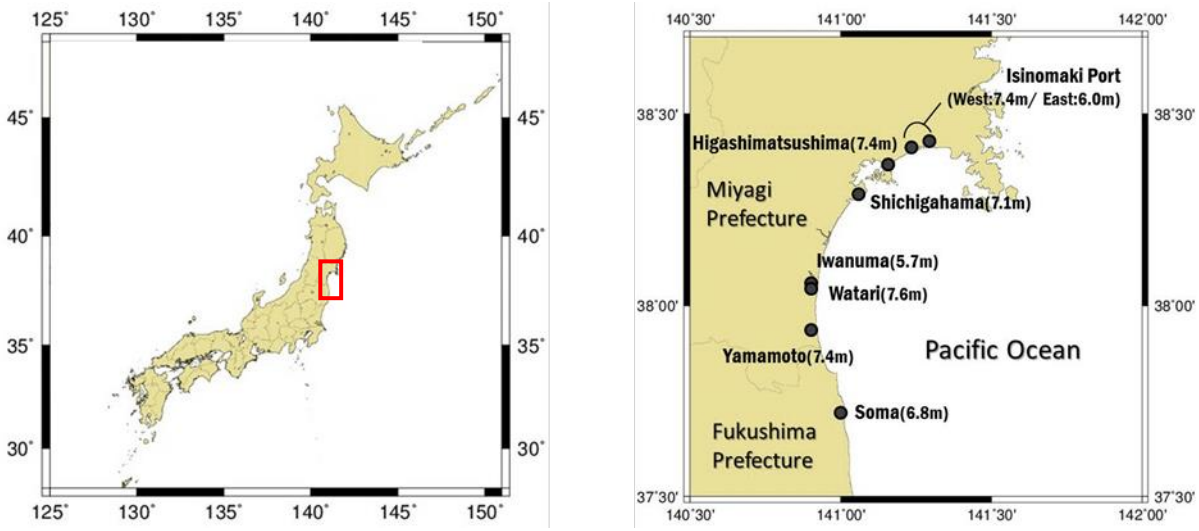
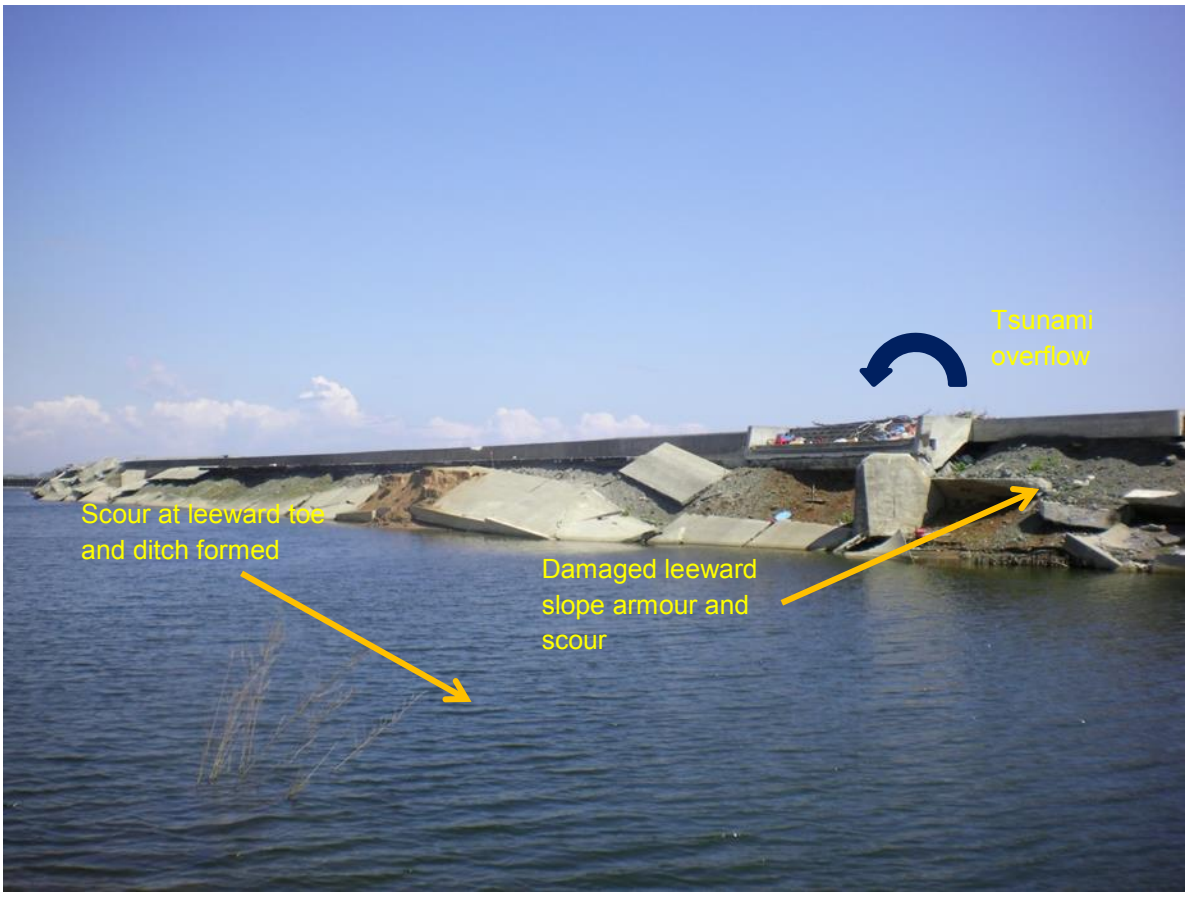


Figure 1. Surveyed locations in Miyagi and Fukushima prefectures after the 2011 Tohoku tsunami with inundation heights.


a)
Tsunami overflow
Scour at leeward toe
Total collapse
Damaged leeward slope armour and scour


Tsunami overflow
Scour at leeward toe and ditch formed
Damaged leeward slope armour and scour

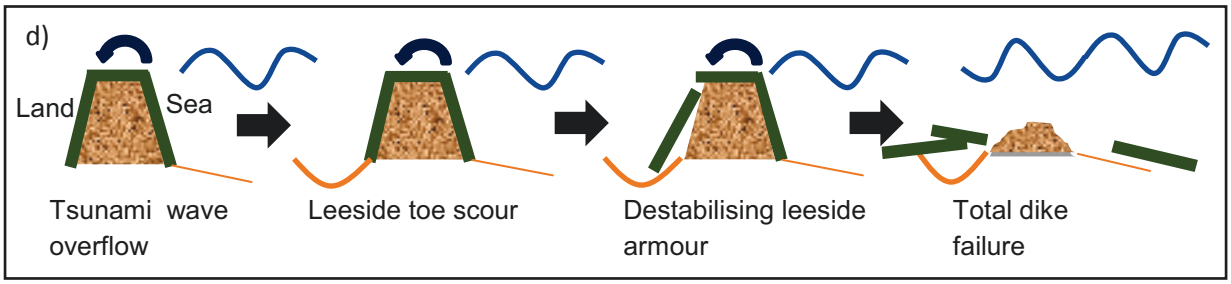
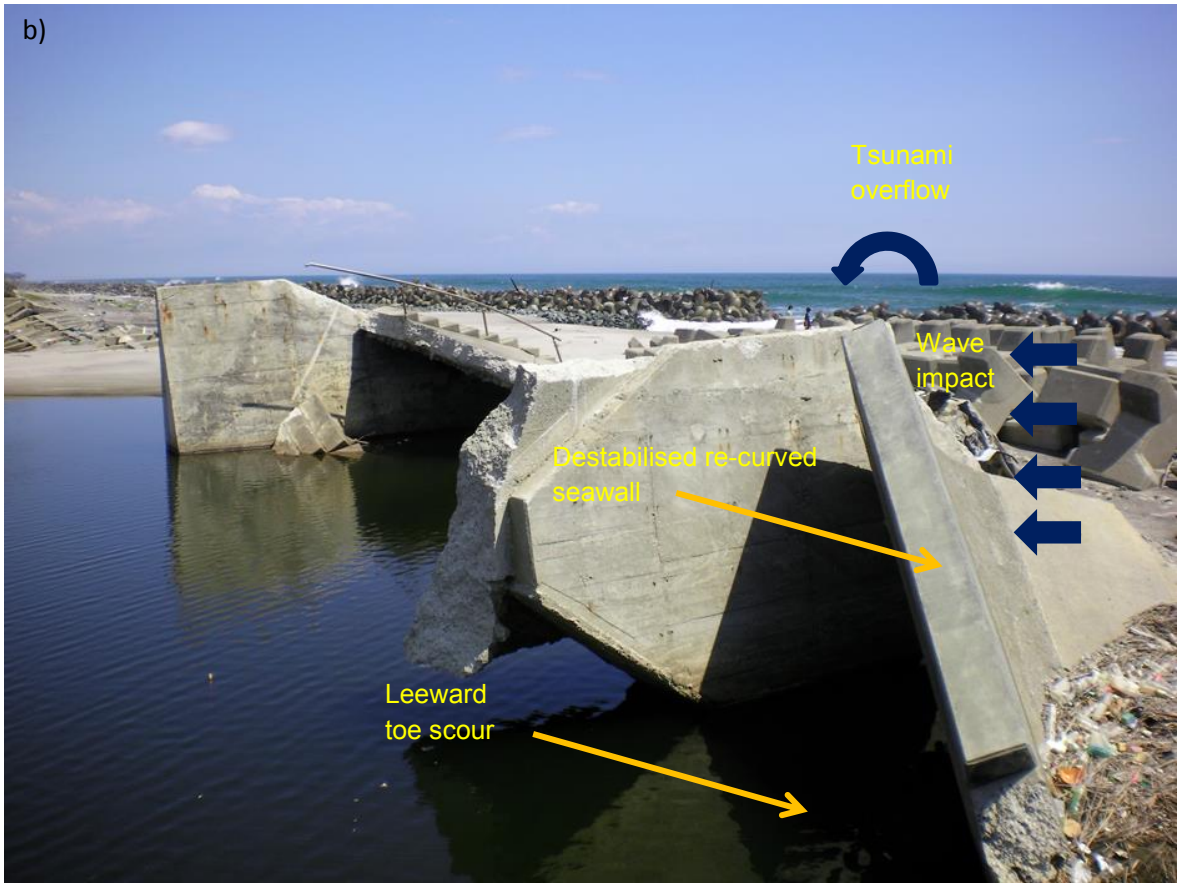


Figure 2. Leeward toe scour in sea dikes: a) Toe scour in sea dike at Iwanuma, b) Toe scour in sea dike at Soma city, c) Toe scour in sea dike at Shichigahama, and d) Physical process of sea dike failure due to leeward toe scour.


a)
Tsunami
overflow
Leeward
toe scour
Wave
impact
Destabilised re-curved
seawall


b)
Tsunami
overflow
Wave
impact
Destabilised re-curved
seawall
Leeward
toe scour

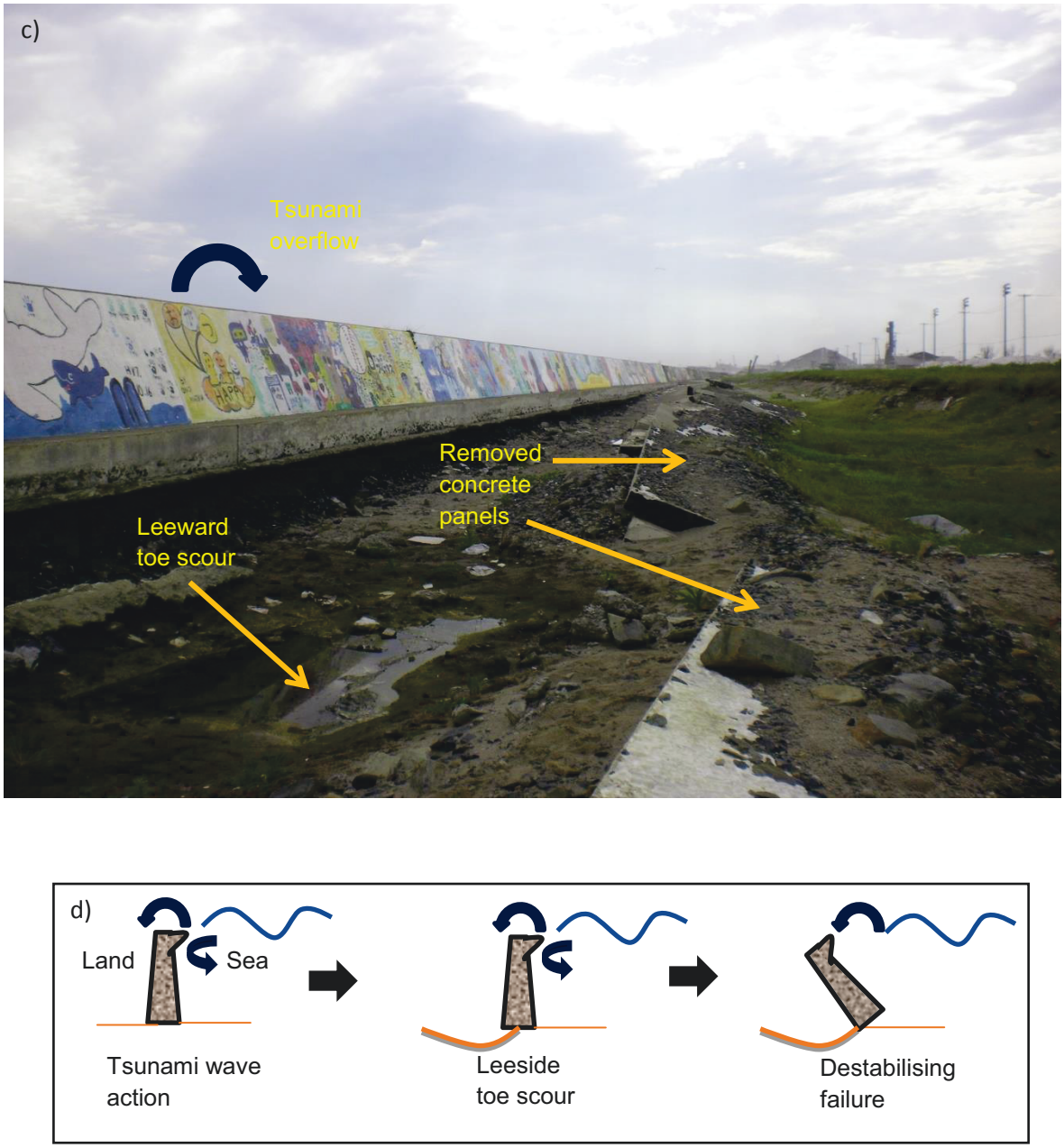
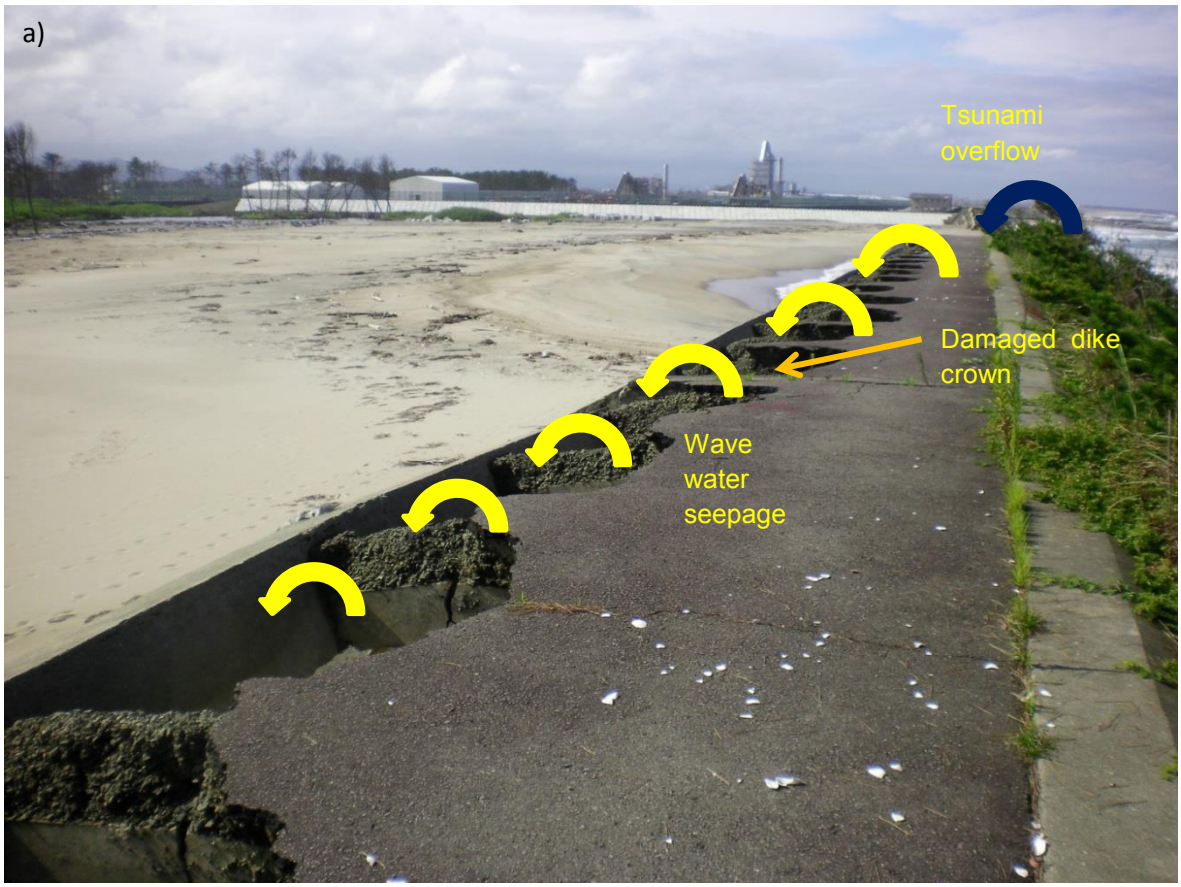
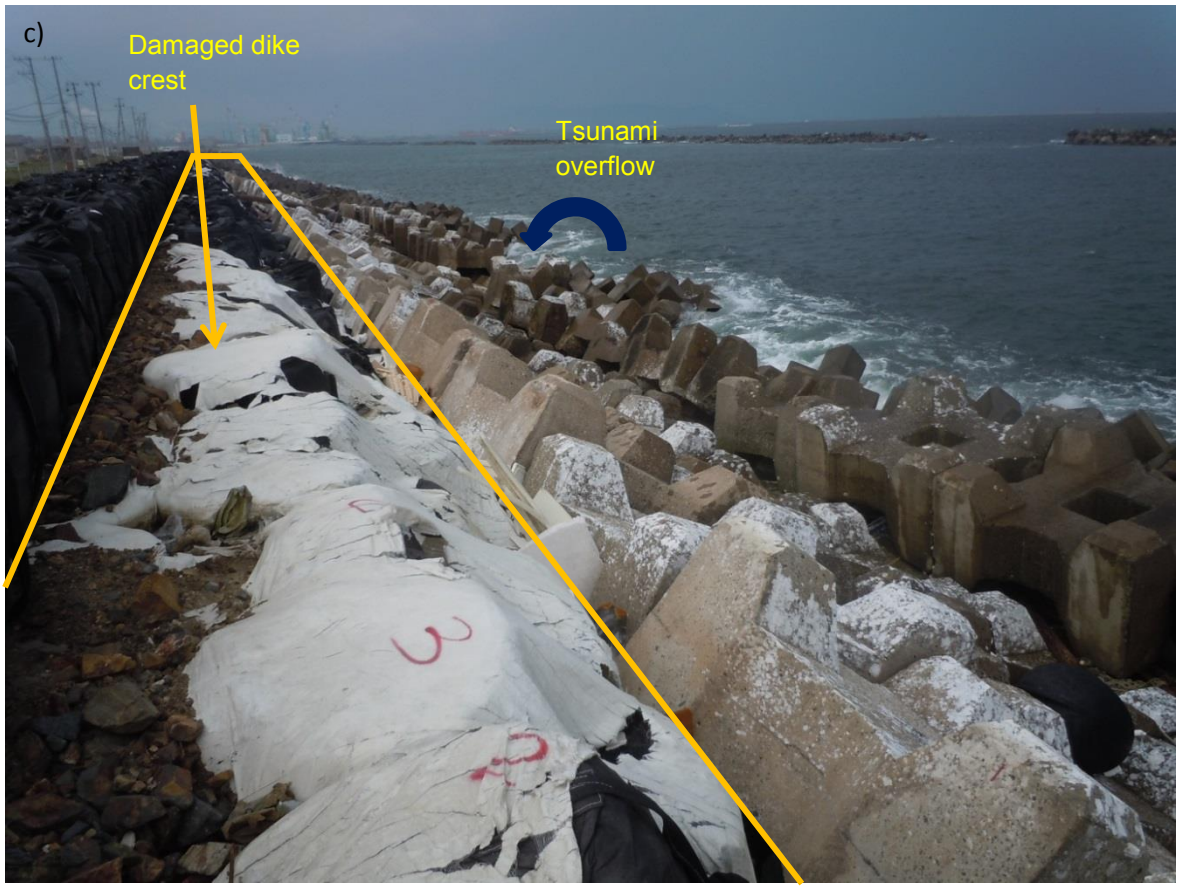
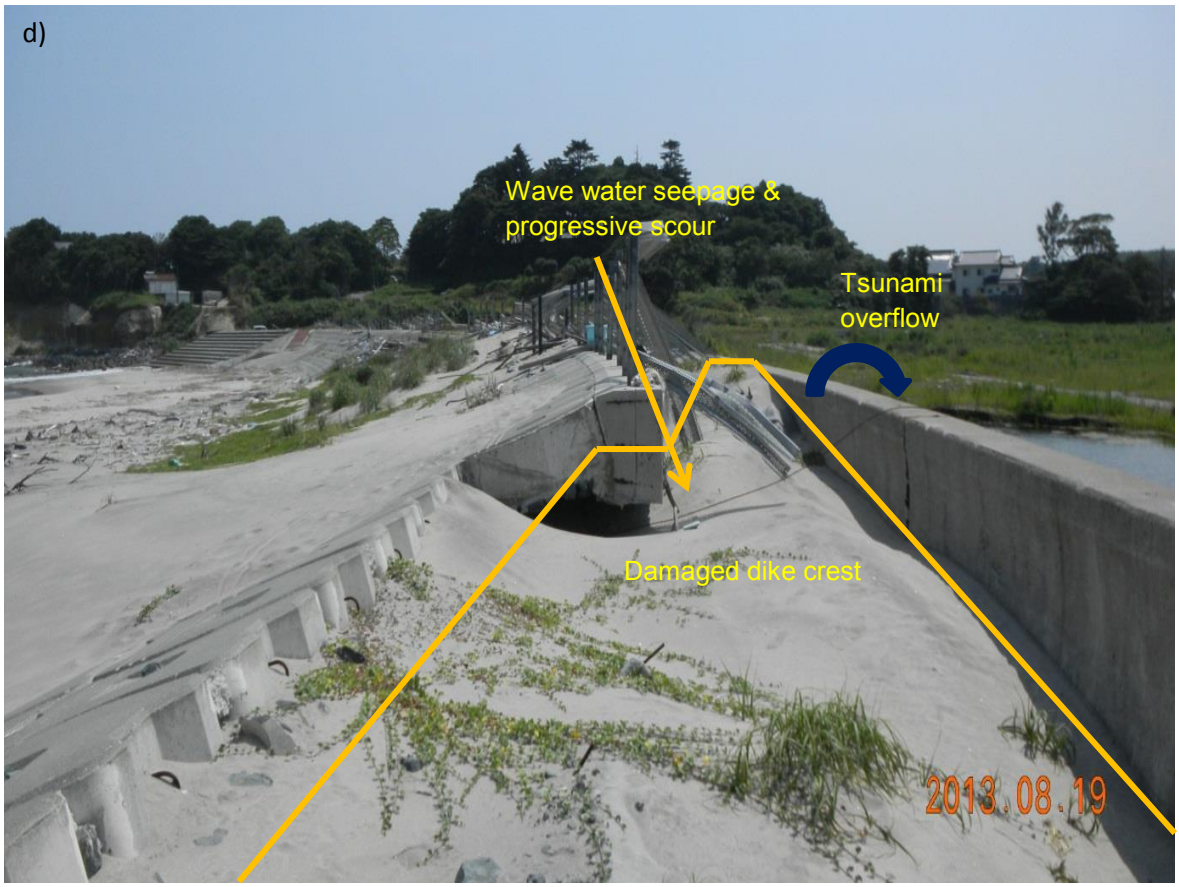


Figure 3. Leeward toe scour in re-curved seawalls: a) Toe scour in re-curved seawall at Watari (North), b) Leeward toe scour in wave wall at soma city, c) Toe scour in re-curved seawall at Ishinomaki (East), and d) Physical process of re-curved seawall failure due to leeward toe scour.


a)
Tsunami overflow
Damaged dike crown
Wave water seepage


b)
Tsunami overflow
Wave water seepage
Massively scoured dike body


c)
Damaged dike crest
Tsunami overflow


d)
Wave water seepage & progressive scour
Tsunami overflow
Damaged dike crest
2013.08.19

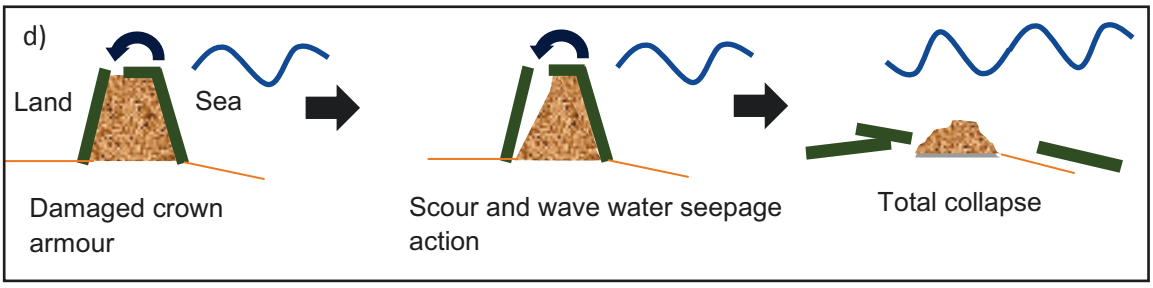


Figure 4. Crown armour failure: a) Top view of damaged dike crest at Yamamoto city, b) Side view of damaged dike crest at Yamamoto city, c) Damaged dike crest at Ishinomaki (West), d) Damaged dike crest at Soma city, and e) Physical process of sea dike failure due crown armour.

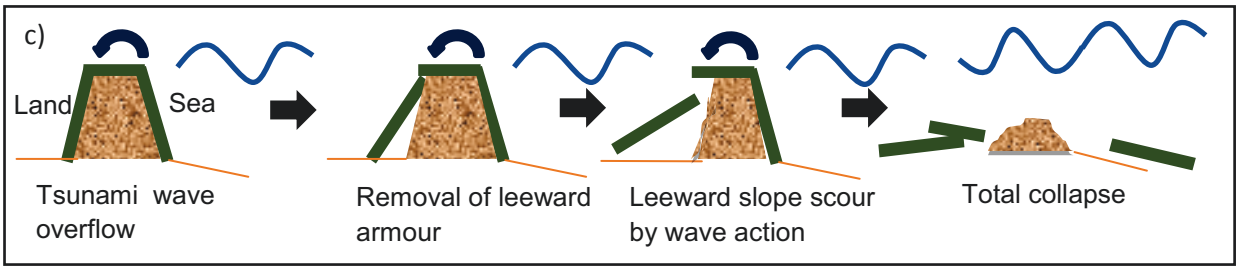


Figure 5. Leeward armour failure: a) Leeward slope armour failure at Ishinomaki (West), b) Leeward slope armour failure at Higashimatsushima, and c) Physical process of leeward slope armour failure.


a)
Tsunami overflow
Seaward slope under construction
Seward toe scour
Tsunami draw-down


b)
Tsunami overflow
Seaward slope under construction

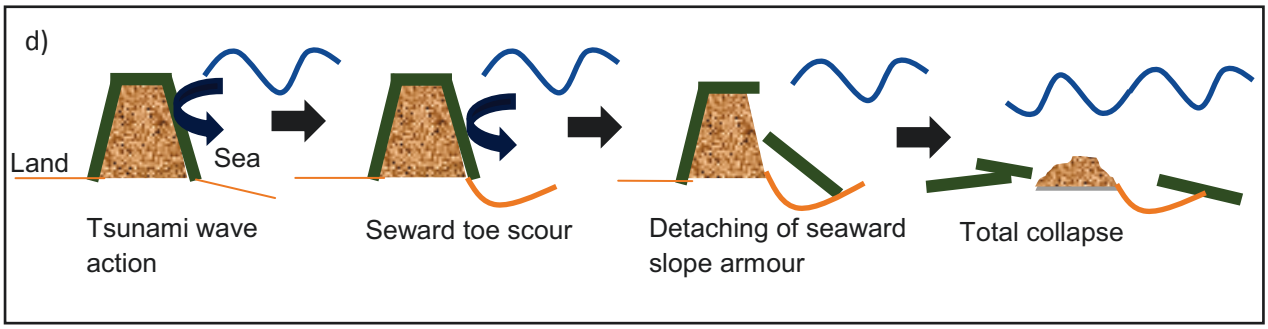
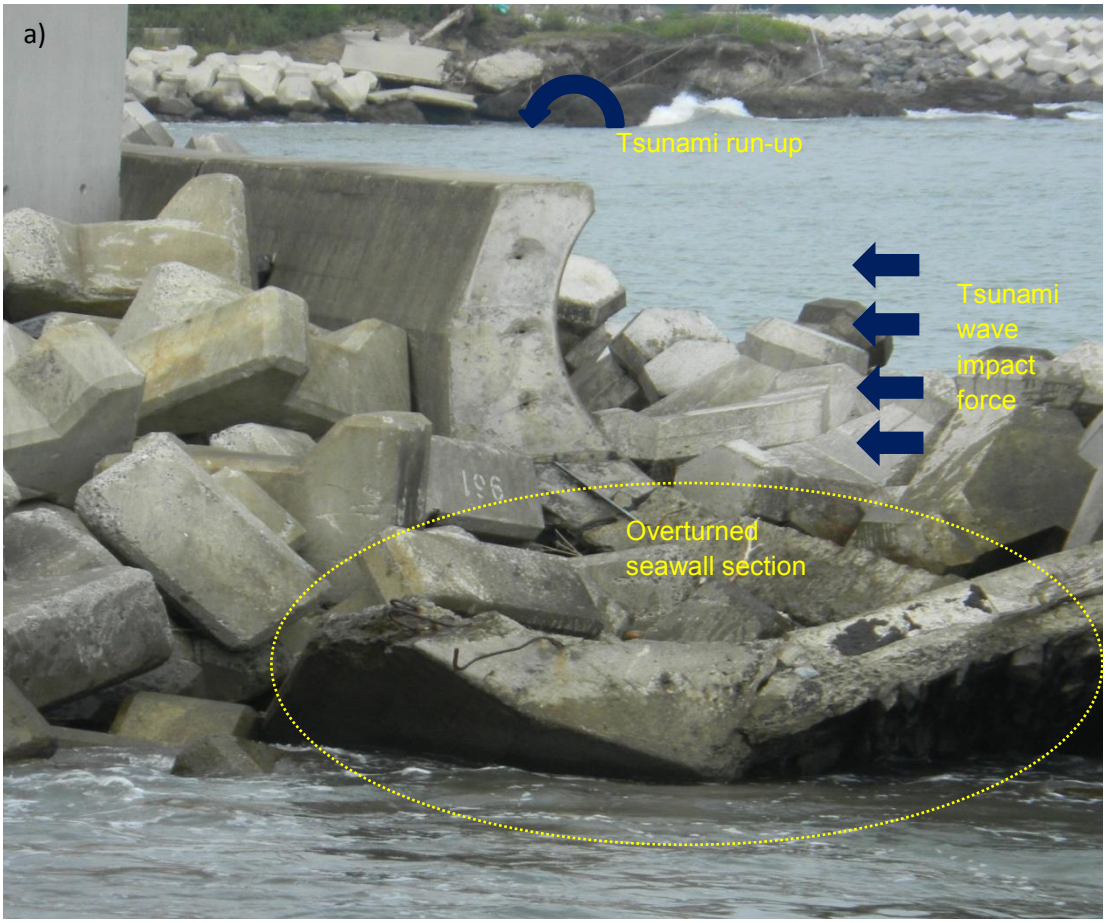


Figure 6. Seaward toe scour and slope armour failure: a) Reformed revetment at Higashimatsushima, b) Reformed revetment at Watari (North), c) Destabilised seaward slope armour at Shichigahama, and d) Physical process of seaward scour and slope armour failure.



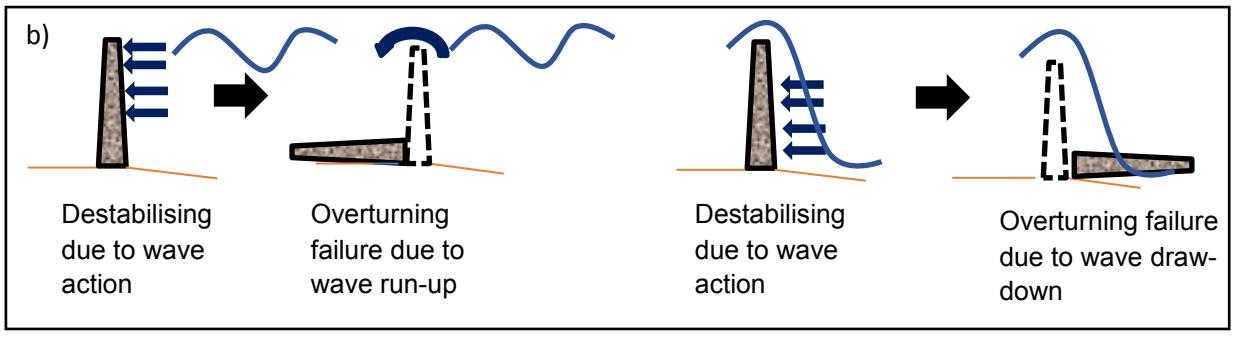


Figure 7. Overturning failure: a) Overturned re-curved wave wall at Kitakami and b) Physical processes of overturning failure due to wave run-up and draw-down.

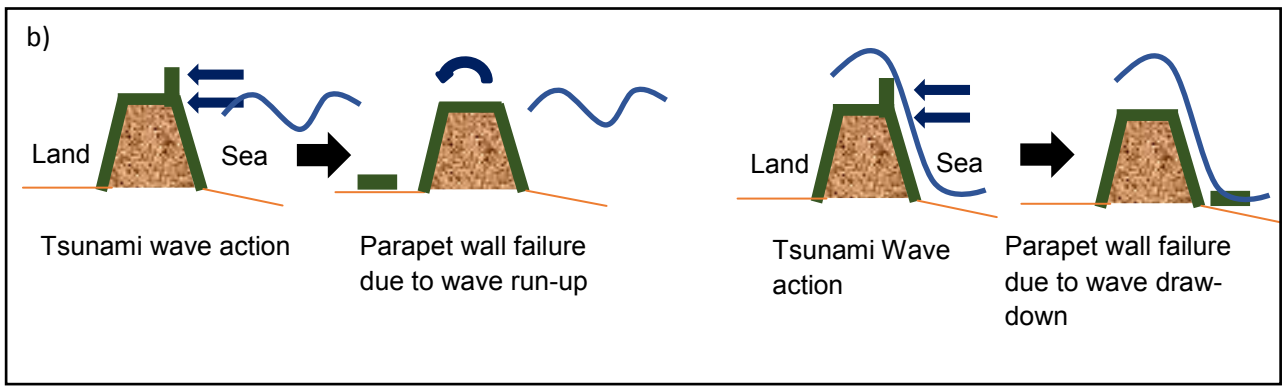


Figure 8. Parapet wall failure: a) Parapet wall failure in a sea dike at soma city and b) Physical processes of parapet wall failure due tsunami wave run-up and draw-down.

a)


Failed breakwater due to missing armour units

b)


Damaged breakwater due to missing armour units

Figure 9. Breakwater failure: a) Offshore breakwater failure at Watari (North), b) Offshore breakwater failure at Ishinomaki (East), c) and d) Offshore breakwaters at Ishinomaki before and after 2011 Tohoku tsunami (Image Source: Google Earth).

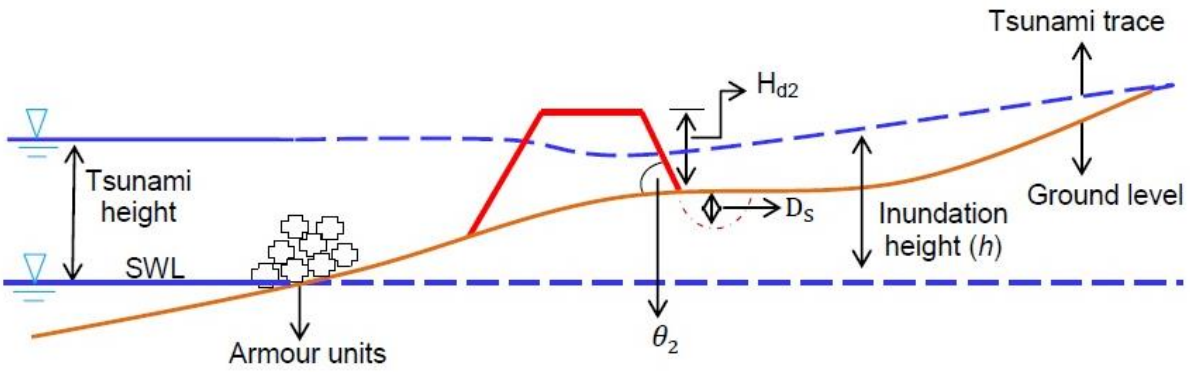


Figure 10. Parameters used in mathematical modelling

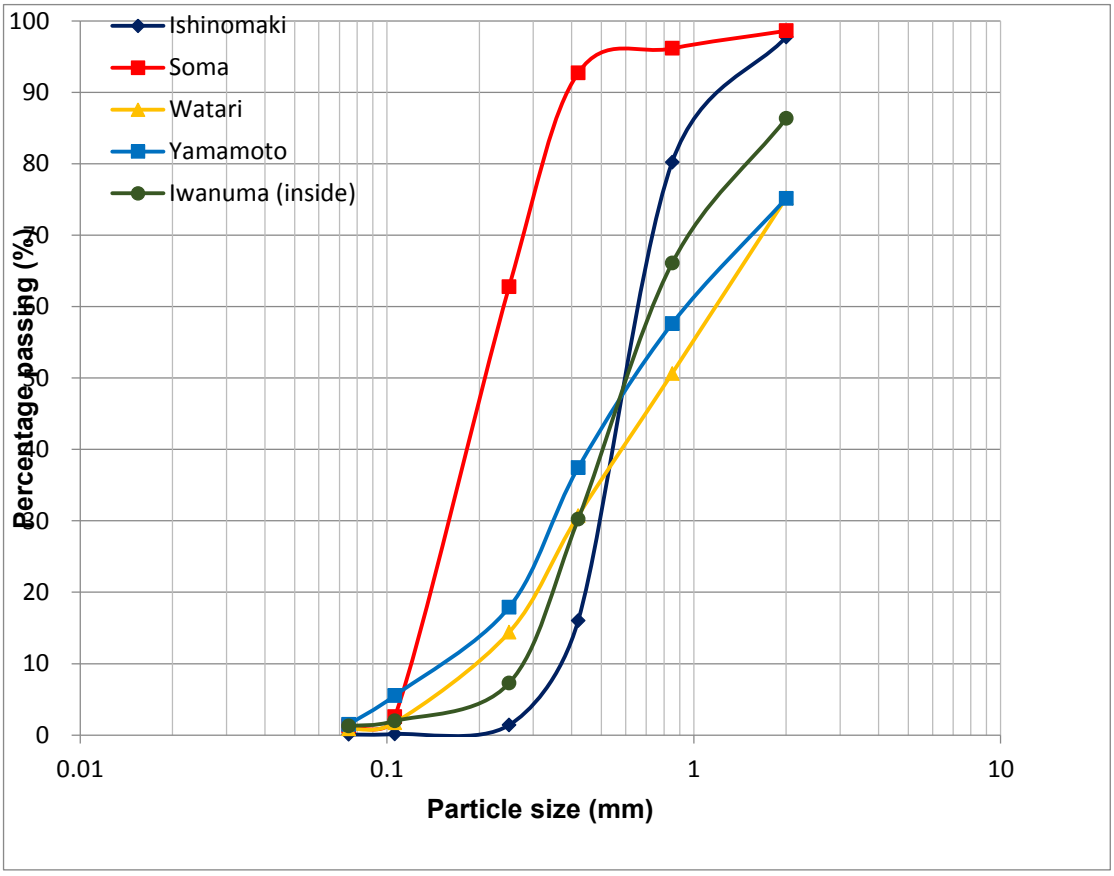


Figure 11. Particle size distribution curves for scour holes at different locations in Miyagi and Fukushima prefectures.

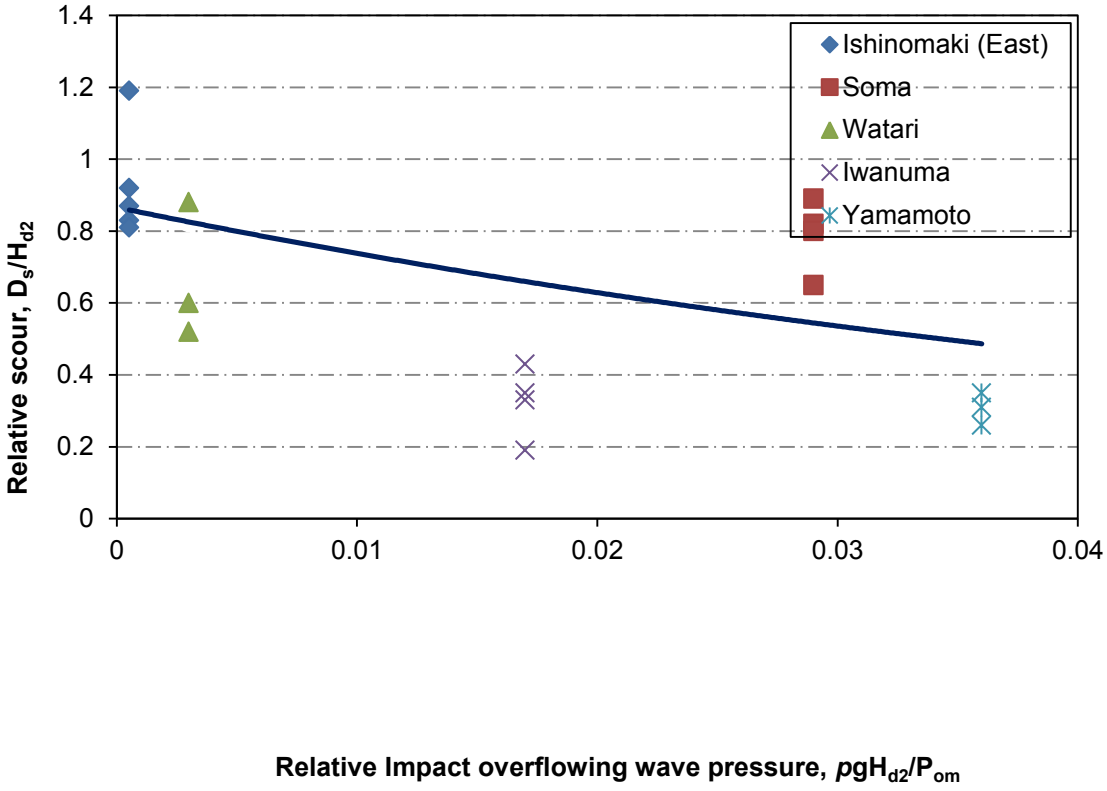


Figure 12. Relationship between relative scour depth and impact overflowing wave pressure

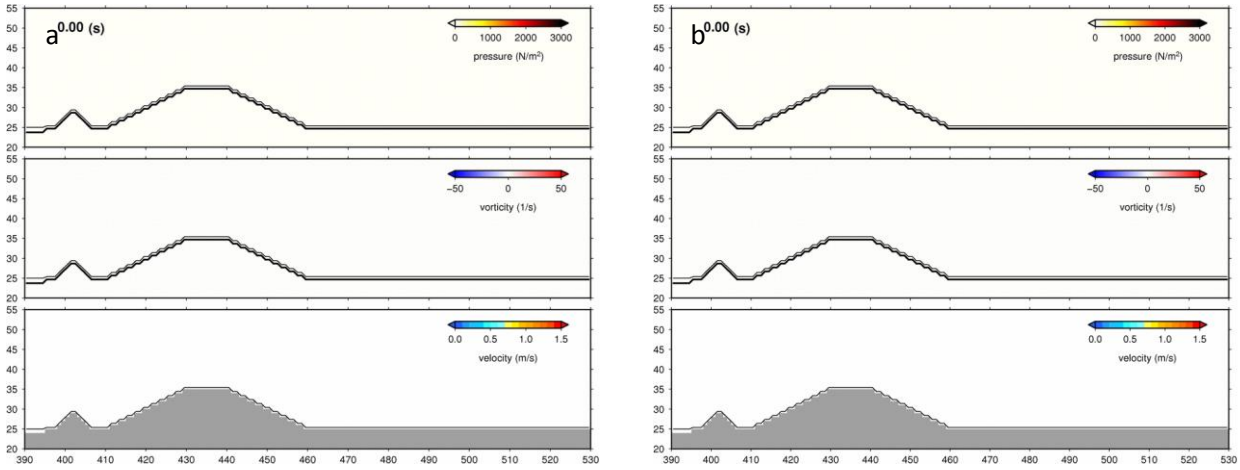


Figure 13. (a) Typical coastal dike with wave wall (Laboratory scale) found in Miyagi and Fukushima prefectures, and (b) Improved coastal dike section with placing artificial armour units in front of seaward slope.

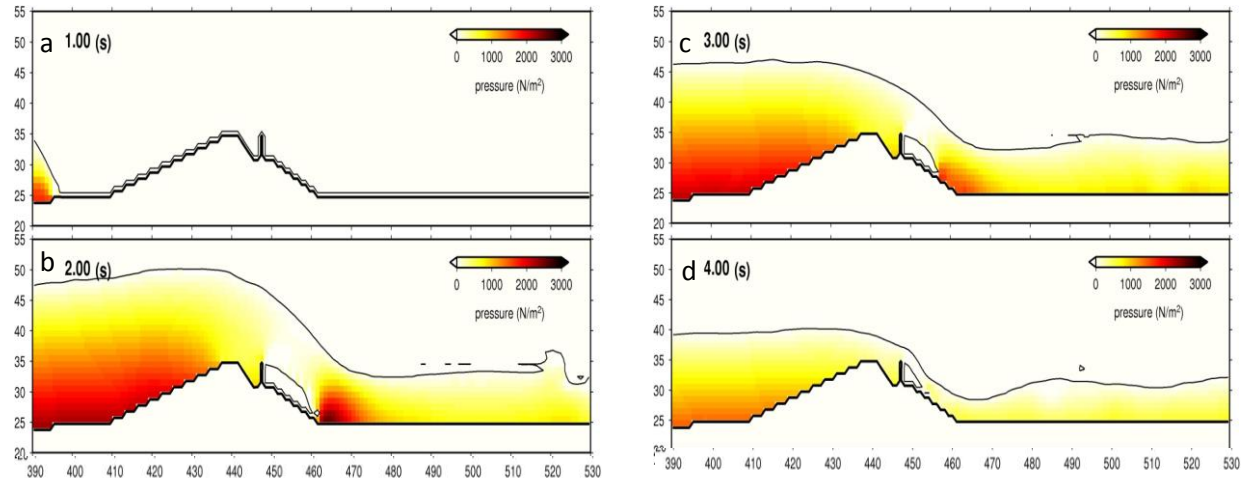


Figure 14. Time variation of overflowing wave pressure around a typical coastal dike with wave wall (Laboratory scale) found in Miyagi and Fukushima prefectures (t=1.0-4.0 s).

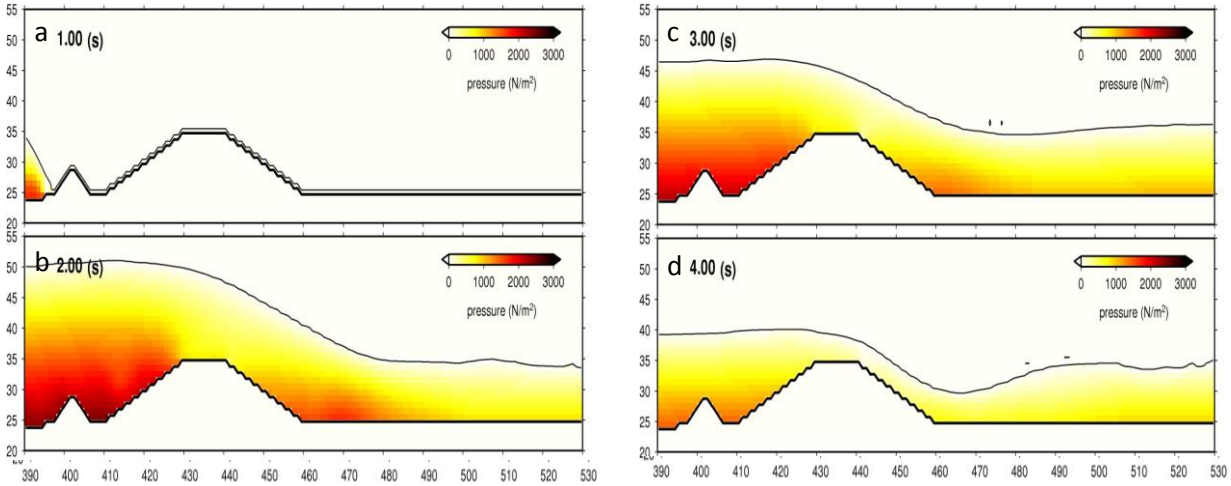


Figure 15. Time variation of overflowing pressures around an improved coastal dike section with artificial armour units placing in front of seaward slope (Laboratory scale) (t=1.0-4.0 s).

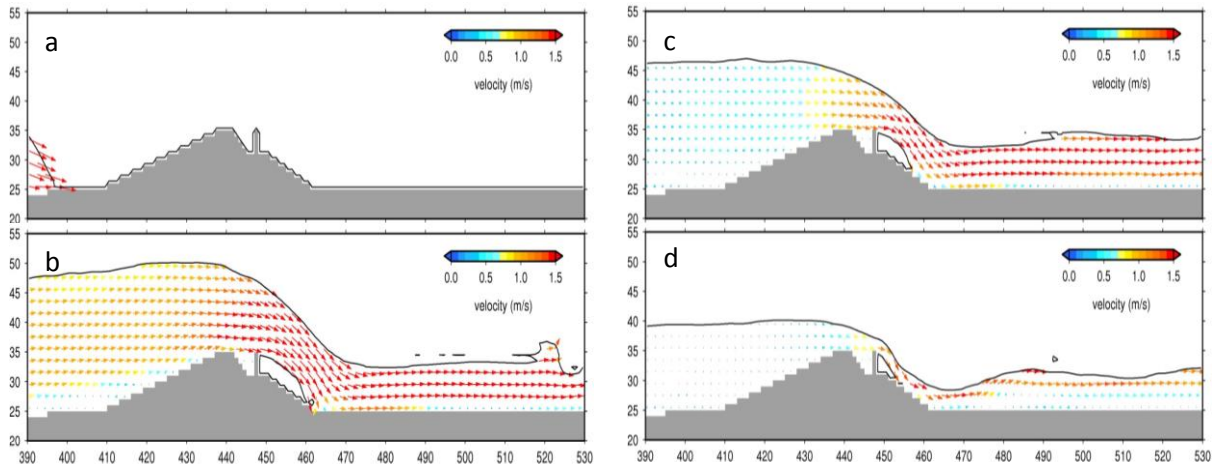


Figure 16. Time variation of velocities around a typical coastal dike with wave wall (Laboratory scale) found in Miyagi and Fukushima prefectures (t=1.0-4.0 s).

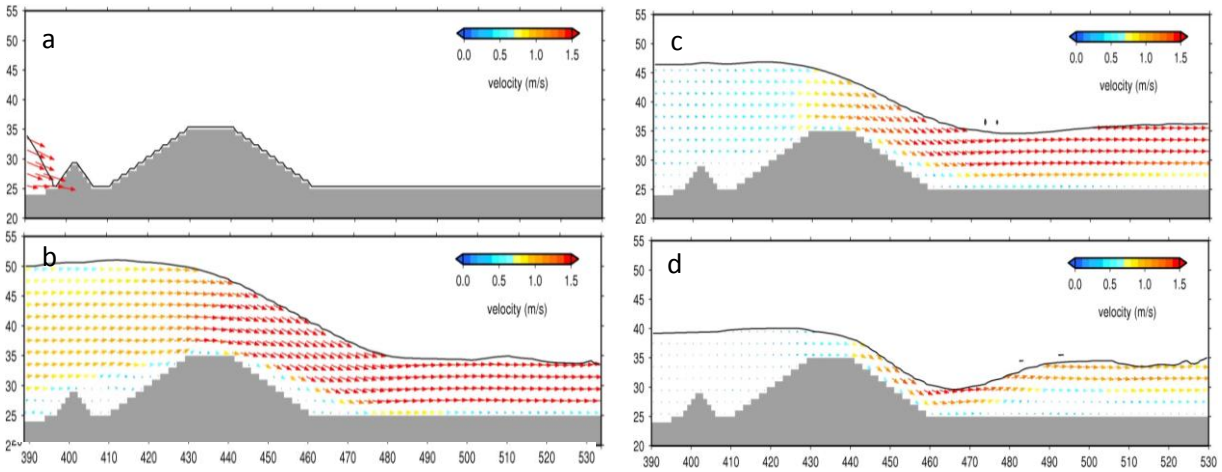
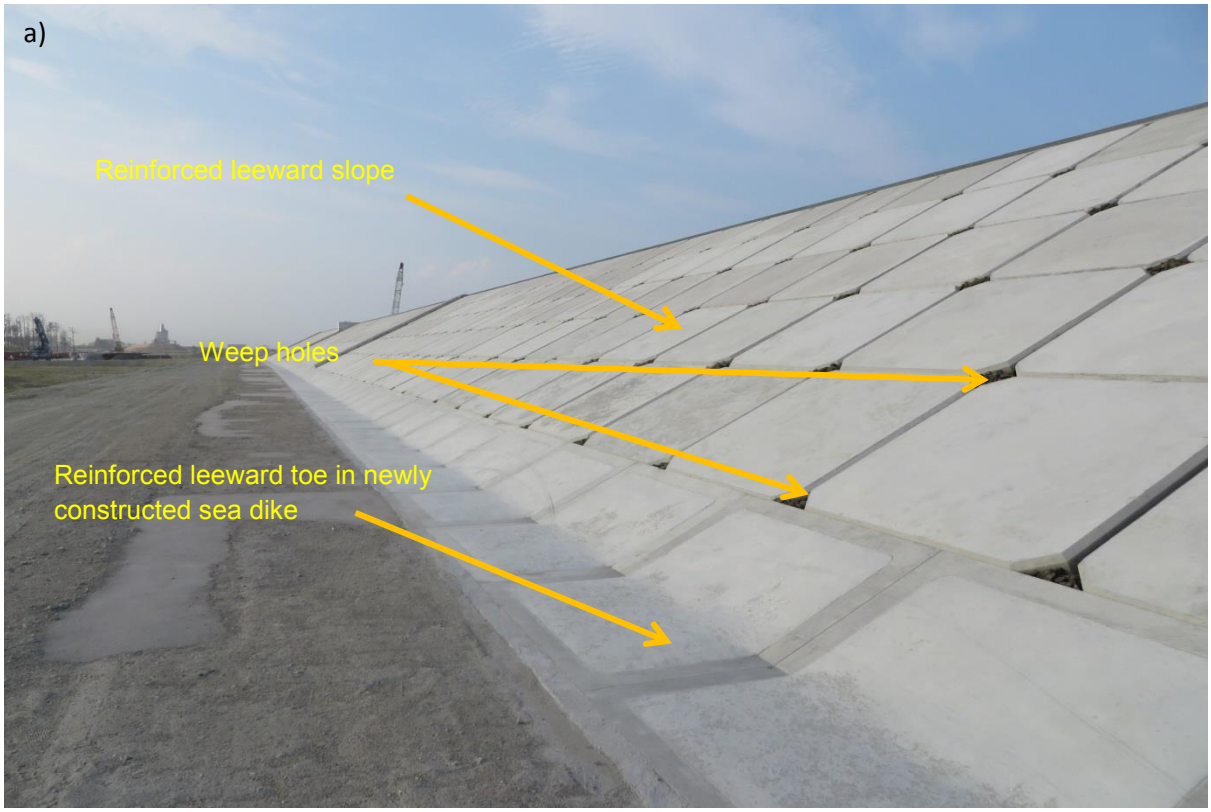
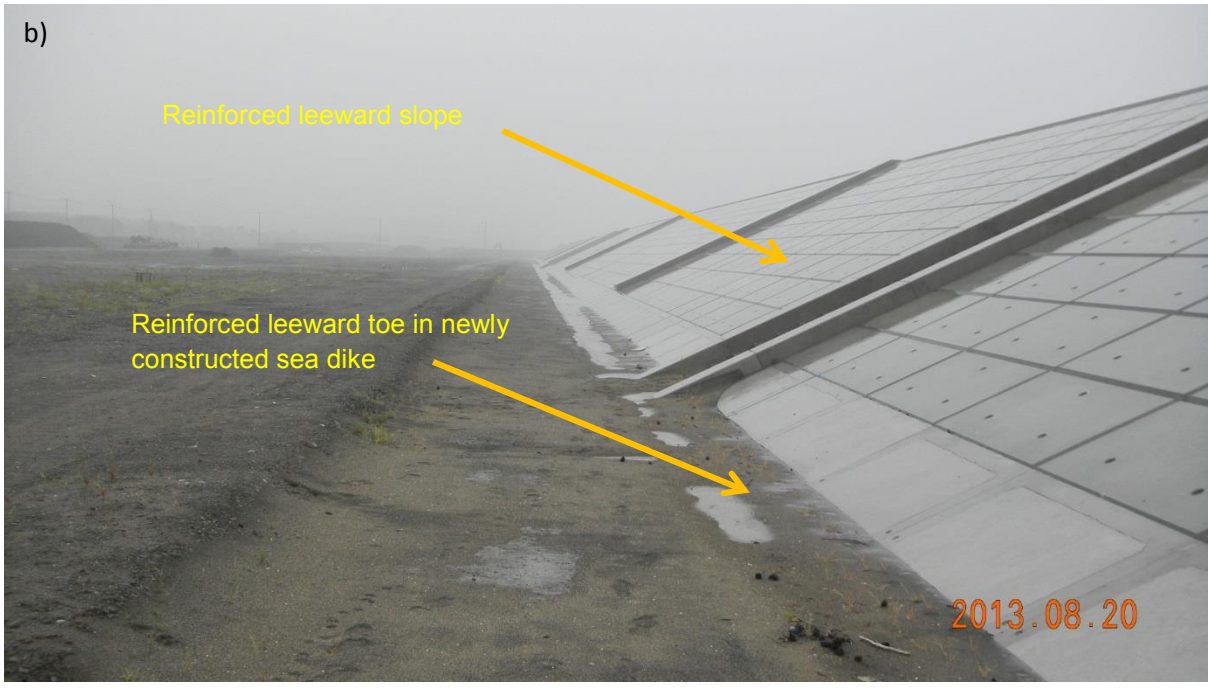


Figure 17. Time variation of velocities around an improved coastal dike section with artificial armour units placing in front of seaward slope (Laboratory scale) (t=1.0-4.0 s).

a)


Reinforced leeward slope
Weep holes
Reinforced leeward toe in newly constructed sea dike

b)


Reinforced leeward slope
Reinforced leeward toe in newly constructed sea dike
2013.08.20

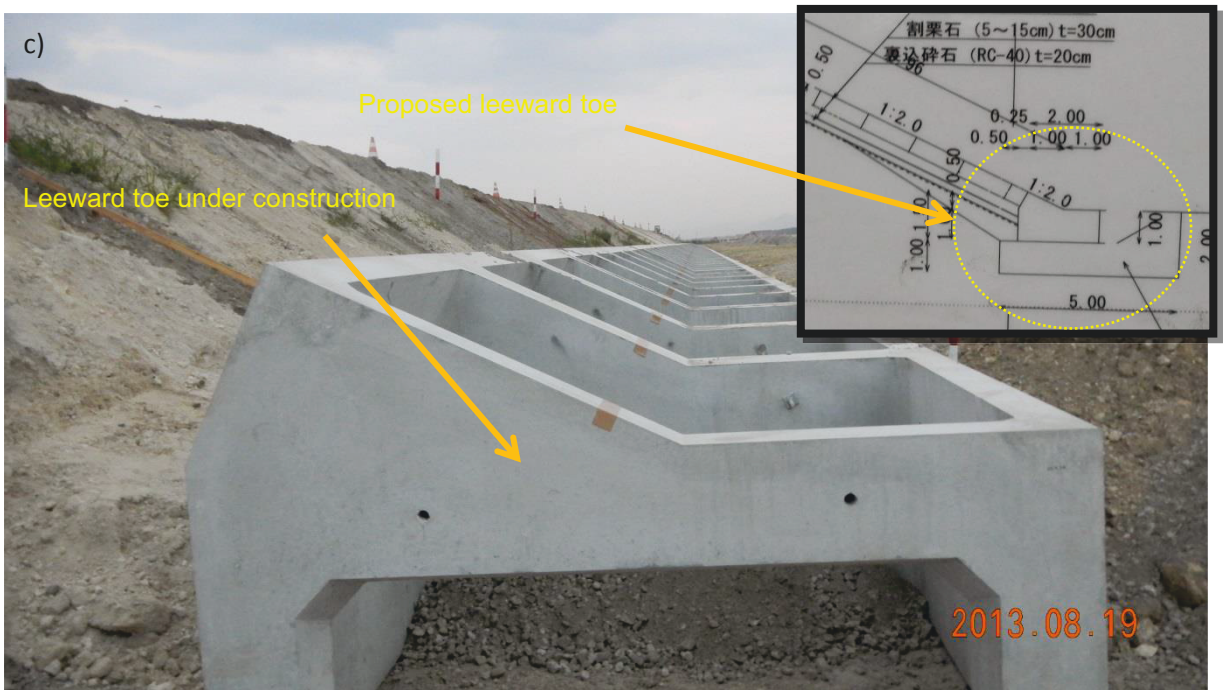


Figure 18. Mitigation measures for leeward toe scour and leeside slope failure: a) Newly constructed sea dike at Yamamoto, b) Newly constructed sea dike at Iwamuma, and c) Sea dike under construction at Watari (North).

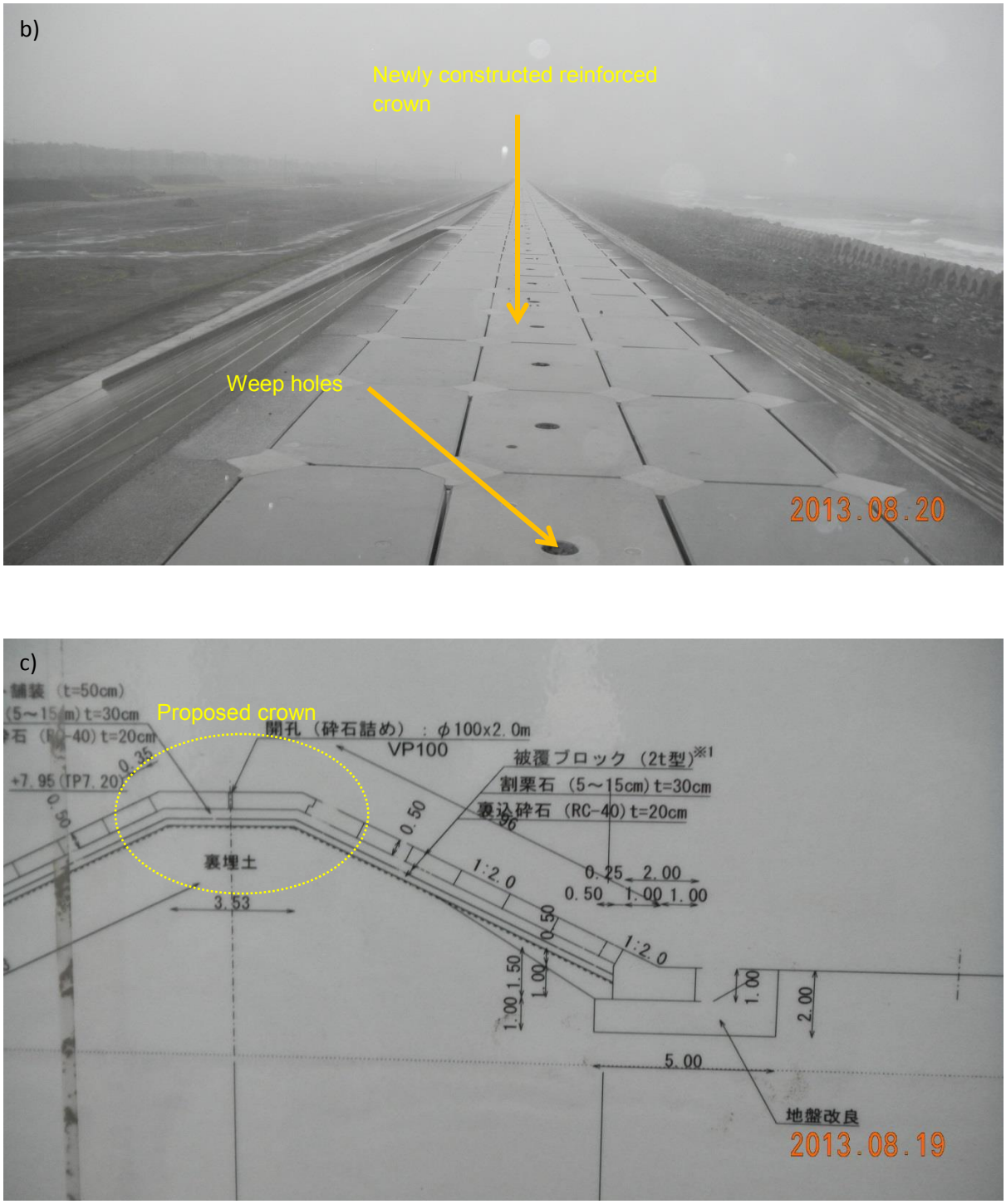
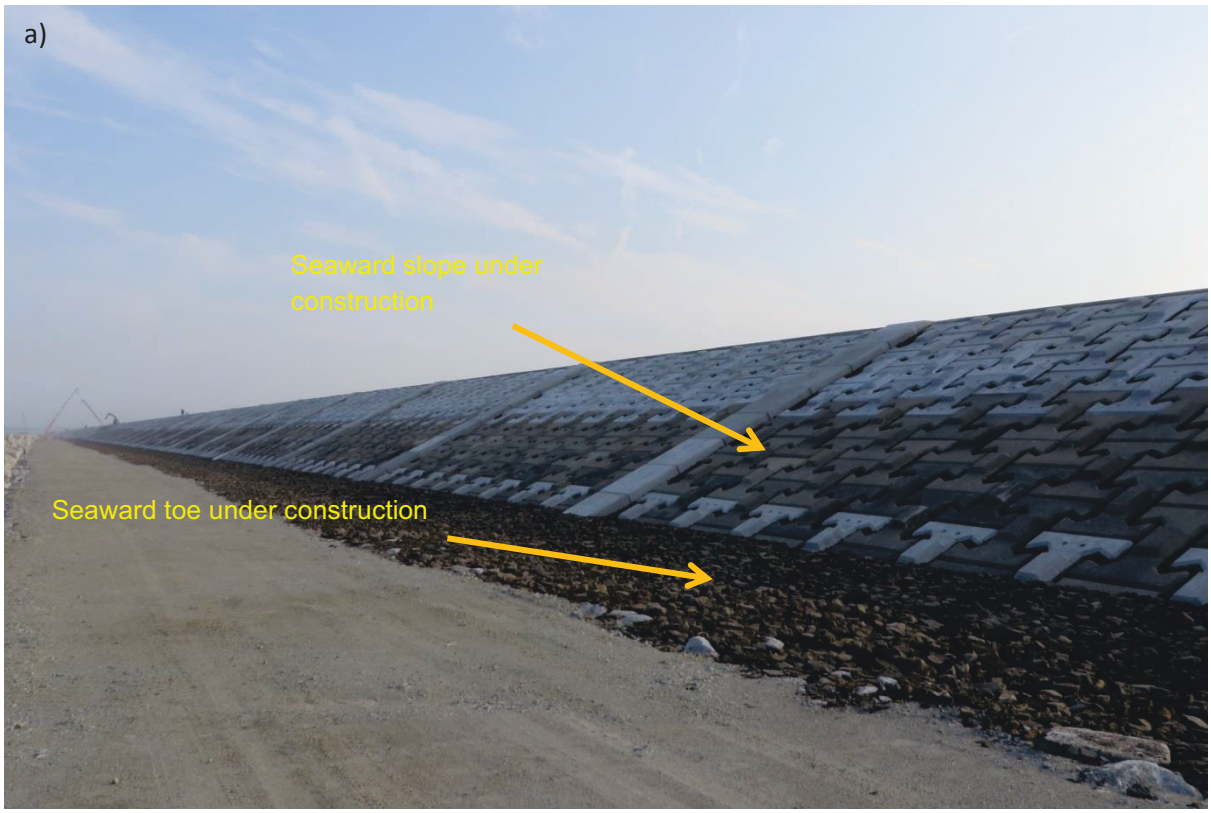
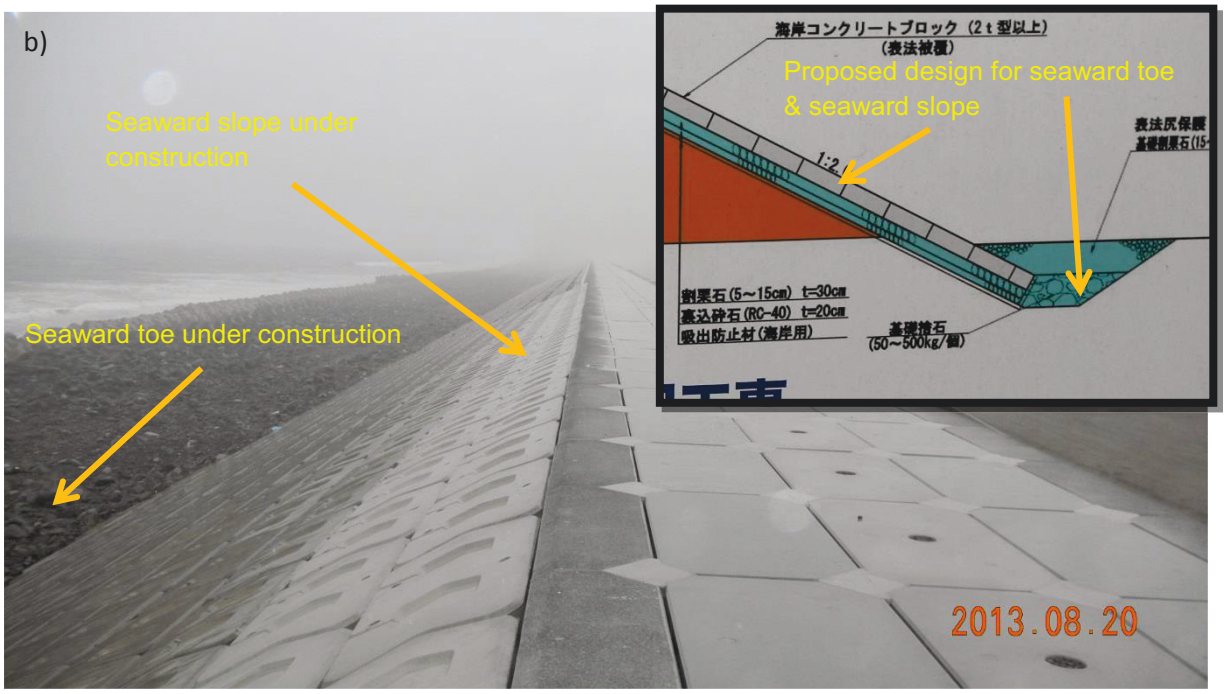


Figure 19. Mitigation measures for the crown armour failure: a) Newly constructed crown in sea dike at Yamamoto, b) Newly constructed crown in sea dike at Iwanuma, and c) Proposed crown at Watari (North).

a)


Seaward slope under construction
Seaward toe under construction

b)


Seaward slope under construction
Seaward toe under construction
海岸コンクリートブロック（2ｔ型以上）
（表法被覆）
Proposed design for seaward toe & seaward slope
1:2
表法尻保護
基礎割栗石(15-
割栗石(5～15cm) t=30cm
裏込砕石(RC-40) t=20cm
吸出防止材(海岸用)
基礎捨石
(50～500kg/個)
2013.08.20

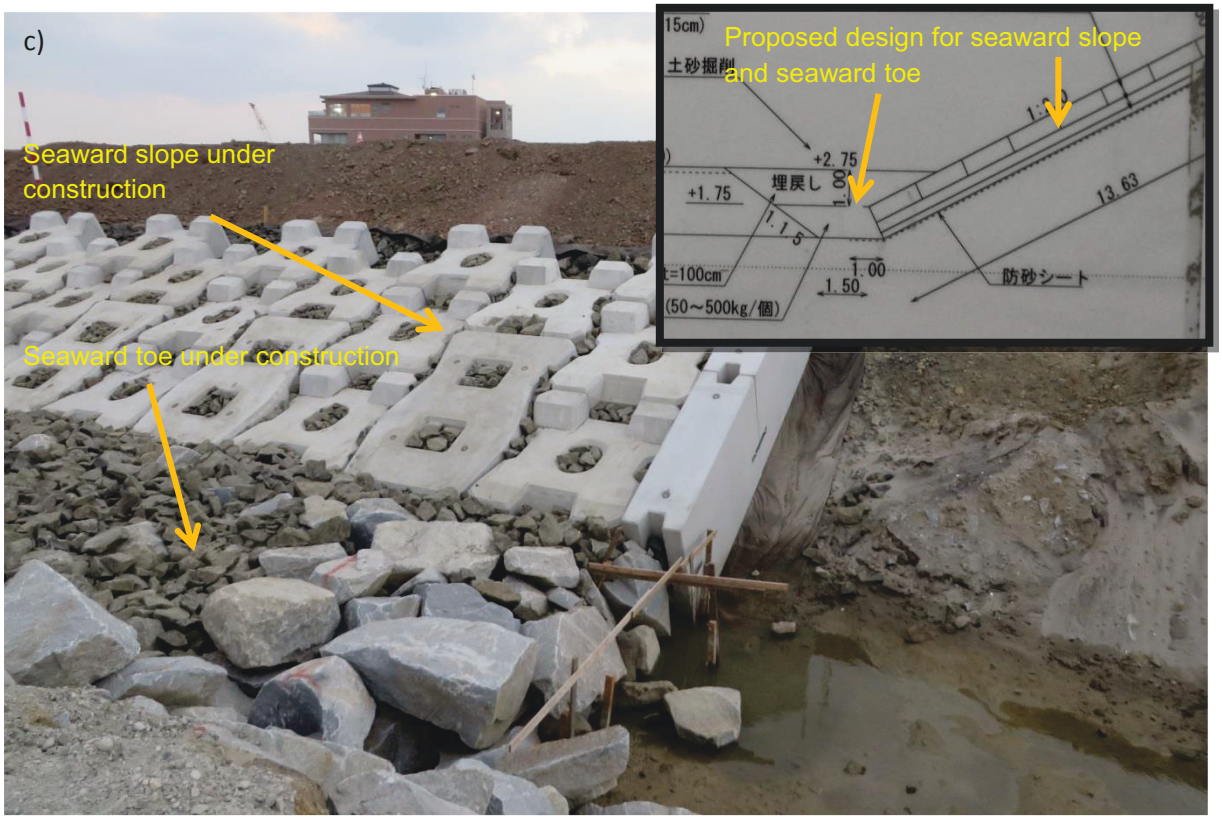


Figure 20. Mitigation measures for the seaward slope armour and toe failure: a) Newly constructed seaward slope and proposed seawrad toe construction at Yamamato, b) Seaward slope and toe under construction at Iwanuma, and c) Seaward slope and toe under construction at Watari (Noth).