Building Surveyors Conference 2016:

Innovative Technologies in Building Surveying

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Latest Research and Studies for Water Leakage Detection

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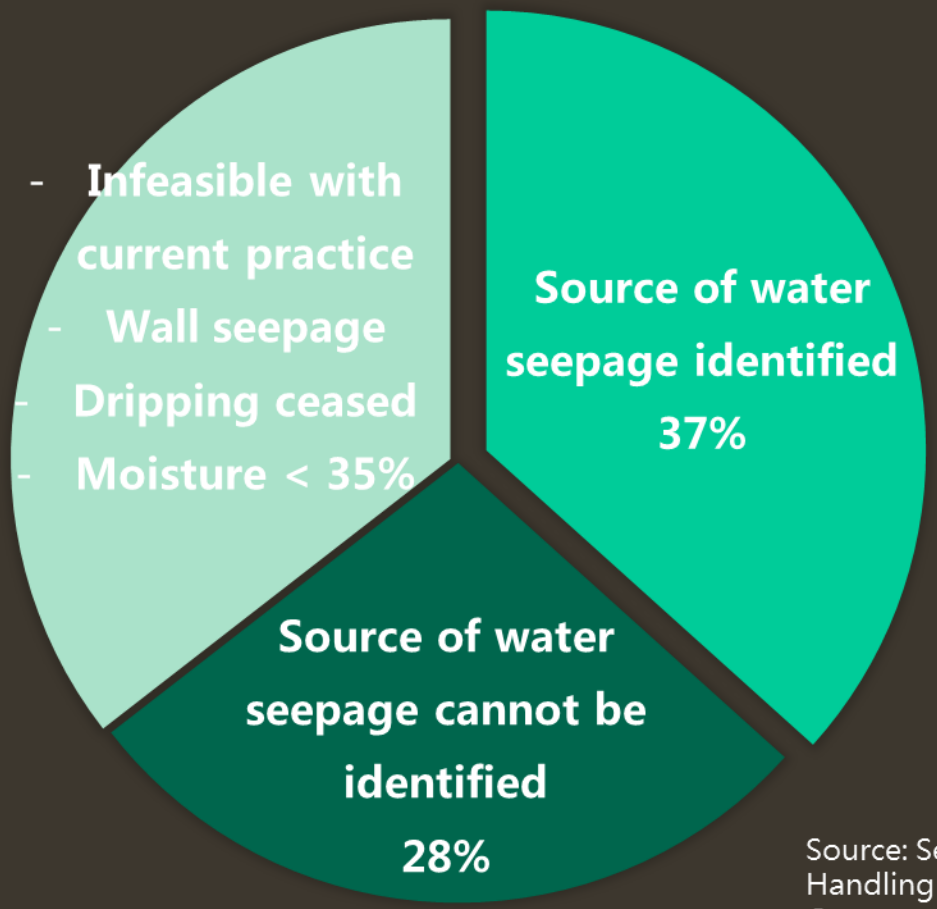
Significance of Water Seepage in Building

- Health hazard – Exp: 2003 SARS spreading through leaky drains in Amoy Gardens
- Structural Safety – Exp: 2010 Building collapse in Ma Tau Wai Road
- Fire hazard – Exp: 2012 Fa Yuen Street fire due to elective short-circuiting
- Falling Concrete – from external facade, internal ceiling, etc. due to delamination or RC deterioration

Administration of seepage reports

- A. Received by Government (Joint Office)
  1. 3-step investigation
     - Reversed pressure test – on water supply pipes
     - Color water test – on drainage outlets
     - Ponding test (PT) – on suspected floor slab
  2. If surface moisture content <35% or if all tests fail to identify a source, No further action
  3. If source is identified, JO takes statutory action
- B. Not reported to JO,
  1. Settlement between owners concerned
  2. Litigation is last resort

Successful Rate of Investigation by JO (From April 1 to July 31, 2015)



Source: Secretary for Department, HKSARG. LCQ8: Handling of complaints about water seepage in buildings. Government Press Releases. Retrieved from : http://www.info.gov.hk/gia/general/201510/14/P2015101

Worst still…as basis of court decision

- Success case may be false positive, or
- Indeterminate case may be false negative.

System Design Deficiency of Current Method

- Source = Permeable medium

  + Outflow +Water

- Dye transport not equal to hydraulic permeability
- Visibility of dye colour affected by many factors

Factors Affecting Visibility of Dye Colour at Seepage Site

- Inflows and outflows before ponding
- Permeability of concrete
- Capillary force on flow in concrete
- Molecular diffusion of dye in flow field
- Adhesion of dye in the flow path
- Evaporation at concrete surface

Measured Values of Relevant Parameters

- Dye diffusion coefficient

  - Rhodamine B : 0.00349 to 0.00392 mm^2/s

- Evaporation rate : $5.7 - 7.63 \times 10^{-3} kg/hr$

  (>1mm/day in typical bathroom environment)

- Reduction in dye concentration by Adhesion (2hrs immersion): ~101% per m^2 of concrete surface

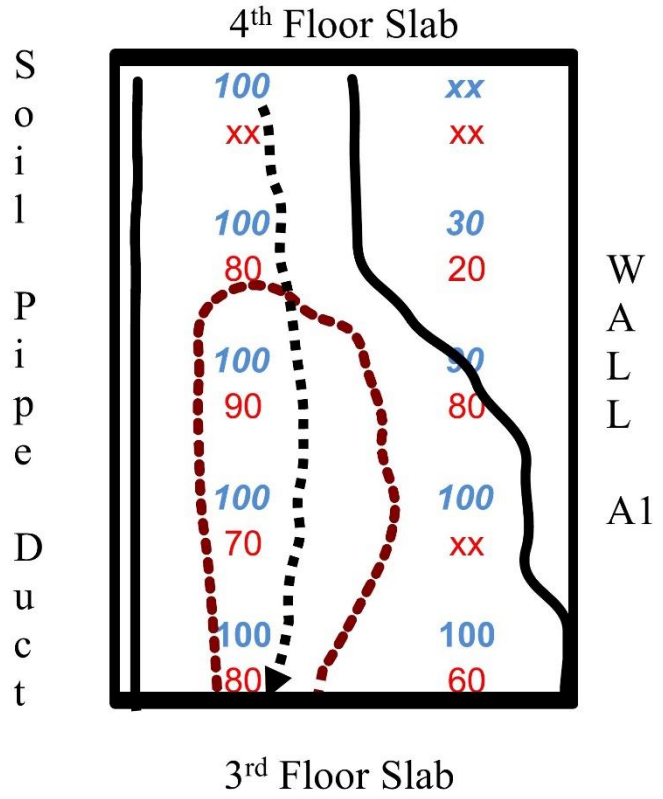
- Capillary rise in concrete : 10.4 to11 mm for C40 concrete in 18 hours

Real Case of Inconclusive PT Indications

- 3 seepage incidents at same location.
- 2 PT conducted during each of Incidents 1 and 2. One positive and one negative in each set of results.
- During 3rd Incident, vertical inflow was found to exist and intruded both upper and lower side of floor slab.
- Diffusion had caused the anomaly. Demonstrated by experiment.

Traditional 1D Flow through Cracks and Construction Joints -- Type 1 Building Seepage

Fig 1. Identifying Flow Path in Wall A1 between 3rd and 4th Floor Slabs



Legend:-

100 / 90 — **Moisture contents on 29/05/10 15/07/10**

80% moisture contour on 29/05/10 15/07/10

Centre line of Flow Path

Notes.

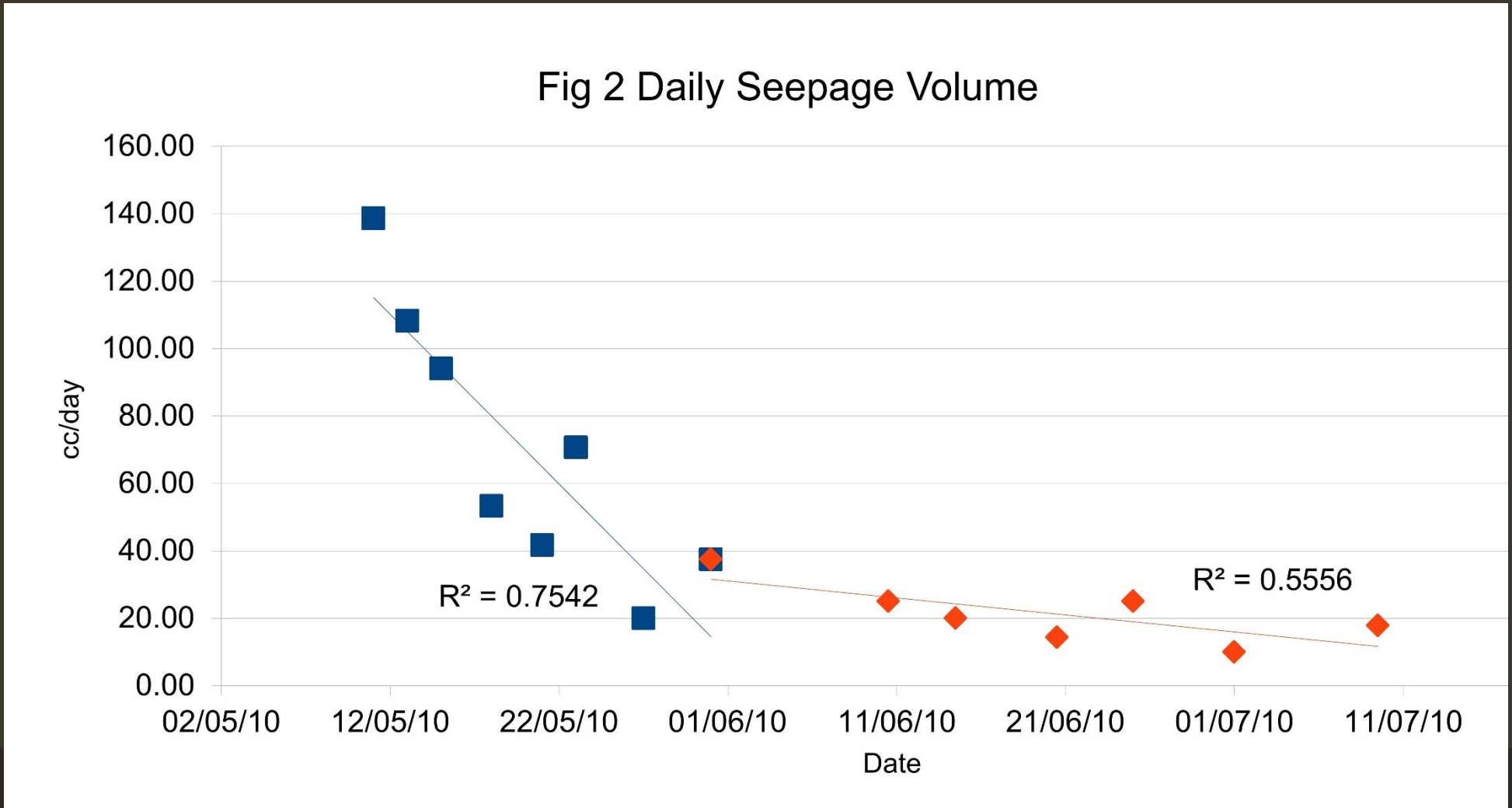
(a) RC wall A1 separates the toilet on 3rd floor and the rear staircase.

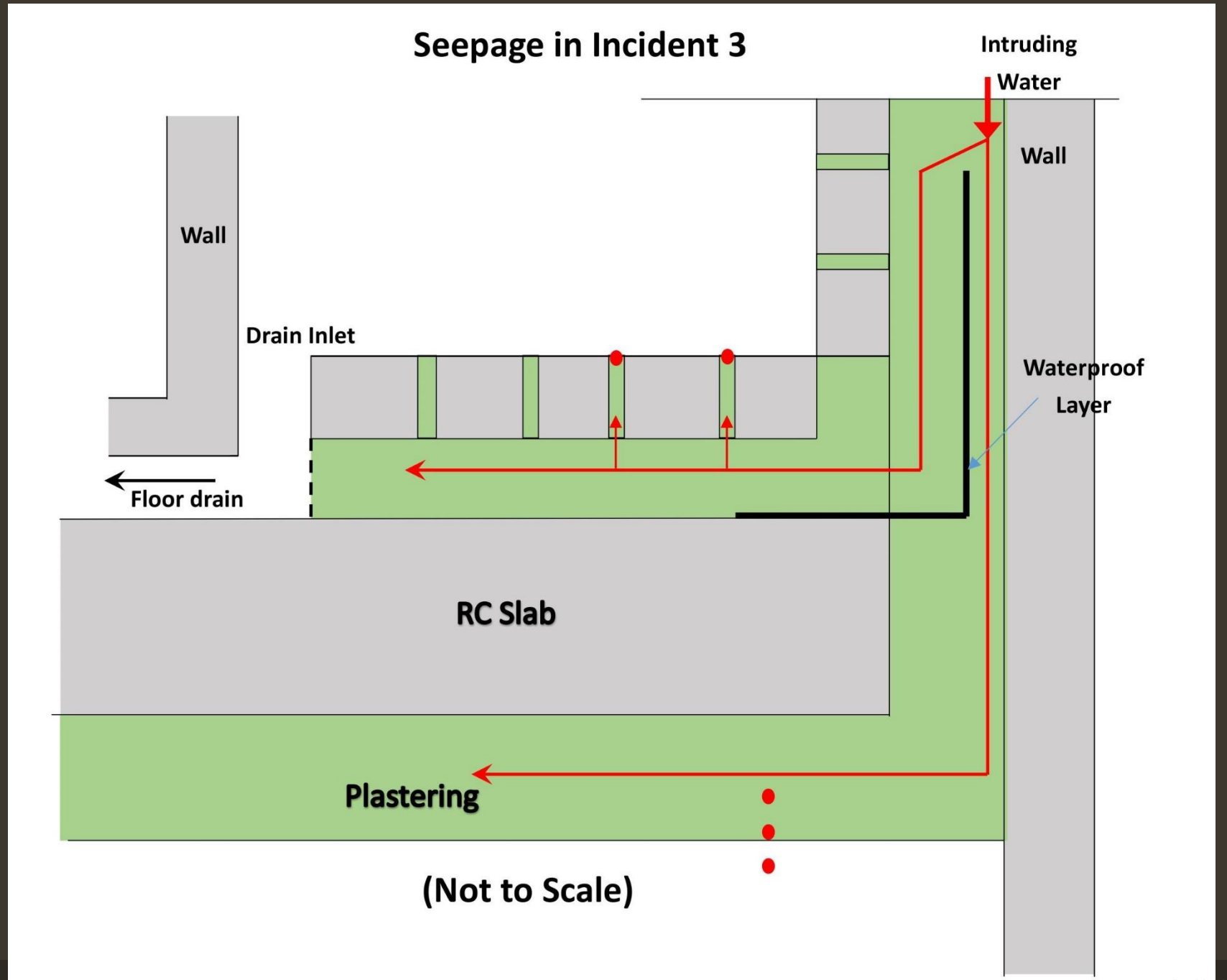
(b) Moisture contour is derived from Relative Moisture Contents measured at 80mm from the interior face (in the toilet)

(c) Portable Roof and Wall Moisture Scanner RWS manufactured by Tramex Ltd, Shankill Co. Dublin, Ireland was used.

(d) Sensitivity scale was set at 2.1.

Traditional 1D Flow through Cracks and Construction Joints -- Type 1 Building Seepage




Seepage in Incident 3
Intruding
Water
Wall
Wall
Drain Inlet
Waterproof
Layer
Floor drain
RC Slab
Plastering
(Not to Scale)

Diffusion Effect

- Co-flowing stream :

  Shorter dye visibility time ↓

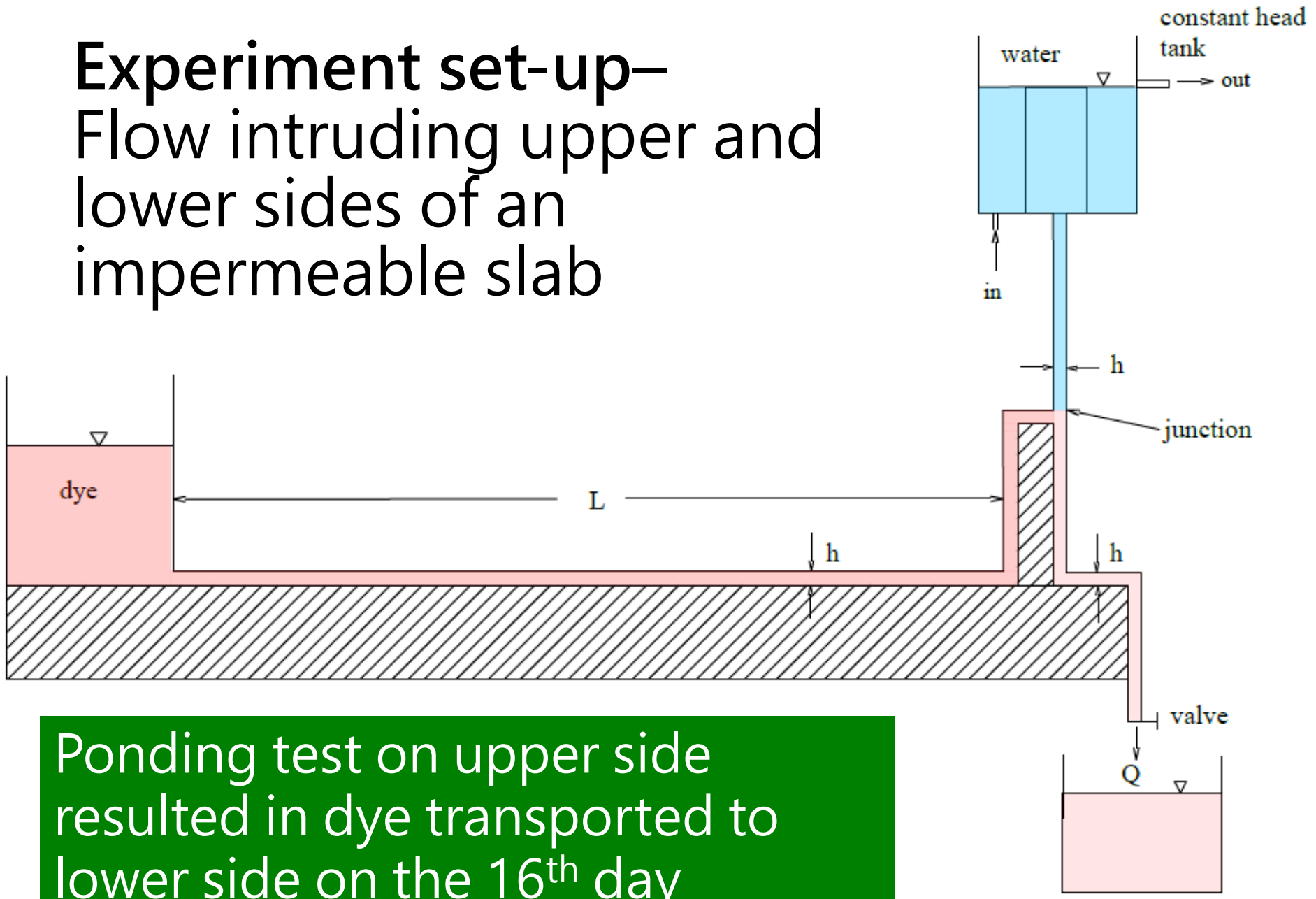
- Counter-flowing stream :

  Dye can still be transported although the max. attainable concentration at the seepage site ↓

- Advection-diffusion equation

$$\frac{C_m(x,t)}{C_0} = \frac{1}{2}\left[1 - \mathrm{erf}\left(\frac{x-ut}{\sqrt{4D_m t}}\right) + \exp\left(\frac{ux}{D_m}\right)\left(1 - \mathrm{erf}\left(\frac{x+ut}{\sqrt{4D_m t}}\right)\right)\right] \quad for\ 0 < t < +\infty$$

Experiment set-up– Flow intruding upper and lower sides of an impermeable slab



Ponding test on upper side resulted in dye transported to lower side on the 16th day

Acceptable level of water tightness in residential buildings

- Wetting time under Normal use < 1 h /day
- Tolerable permeability = 1 / 3600 = 3 x 10^-4 mm/s
- Time for infiltration front to reach bottom of 125 mm slab = 125 / (1/3600) s = 5.2 days

Indications of Ponding Test

- Taking uncertainty factors into account,

Dye visibility time	Indication
$\leq 1\frac{1}{2}$ day	Highly likely inadequate water tightness.
>14 days	Evaporation and Diffusion dominates, Definite negative indication, Adequate water tightness
$1\frac{1}{2}$ day $\leq$ time < 14 days	Inconclusive, New testing method is needed

Purpose of Study

- Develop the new Moisture Scanning Method for general practical application to identify the ingress points of water seepage in buildings.
- Clarify the flow mechanism in residential seepage to help develop policy to prevent seepage.

Slope of Study

- Field studies of seepage in 3 buildings respectively in an urban village, new town and Main urban areas.
- Laboratory studies

Ordinary Concrete in Buildings is Effectively Impermeable

Concrete permeability is correlated with compressive strength

Types of concrete	Permeability rate (mm/s)
9 MPa High permeabilty	$\sim 10^{-3}$
18 MPa Orindary Concrete	$\sim 10^{-4}$
30 MPa Low permeability	$\sim 10^{-6}$

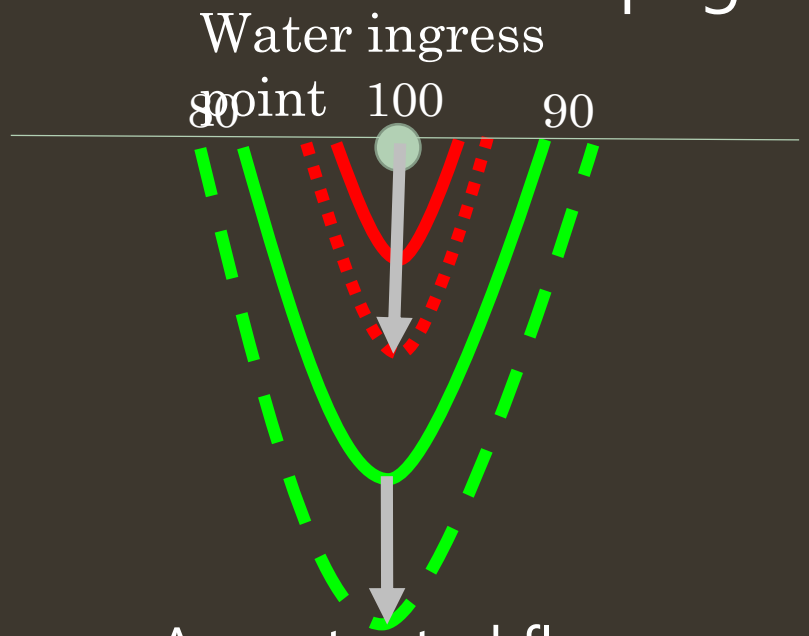
Source: Costa, J. O. (2003). Permeability of concrete: A study intended for the “in situ” valuation using portable instruments and traditional techniques.

Compare with acceptable permeability of 3×10^{-4}

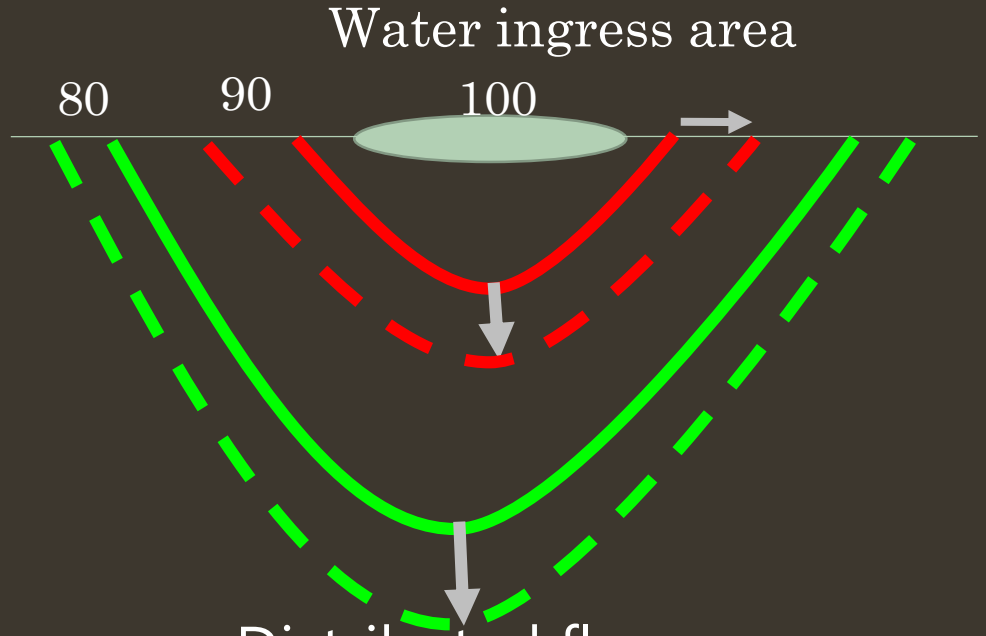
Existence of Seepage = higher permeability or water retaining spots

Principle of new method of moisture scanning to identify flow mode & water ingress point

Wall Seepage – vertical movement



Accentuated flow

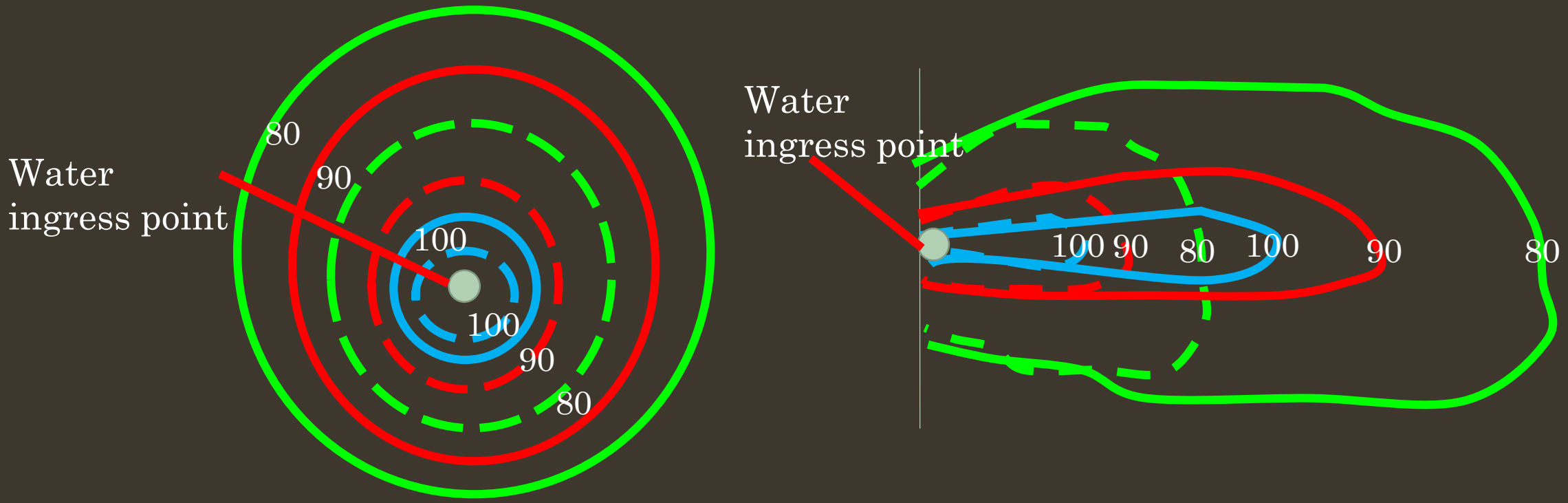


Distributed flow

- 1. The moisture contours at 2 successive time instants can indicate the mode of flow and ingress point.
- 2. Only relative degree of saturation is needed
- 3. Relative moisture contour at a fixed depth below surface can be measured by microwave scanners available in market.

Principle of new method of moisture scanning to identify flow mode & water ingress point

Horizontal movement in slab



Distributed flow

Accentuated flow

- Peak & trough are potential inflow and outflow points,
- Locus of maximum curvature point in moisture contours is accentuated flow path.

Tremex RWS roof and wall scanner

Scanning of Ceiling

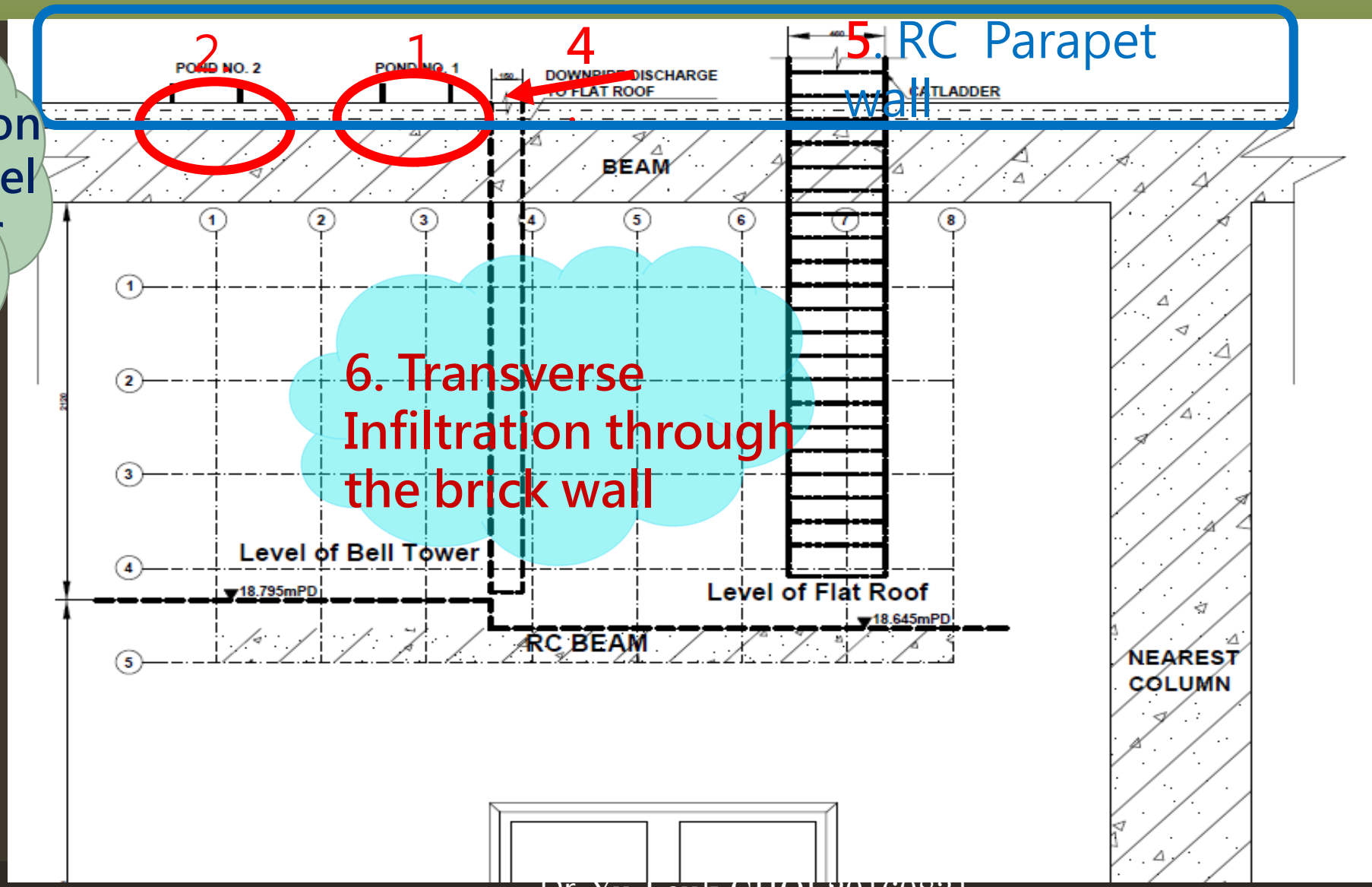
3 Field Studies by Moisture Scanning

1. Wall seepage -- Fanling Case:
   - Where did the wall dampness source from?
   - Why water stain & dust stain only appeared above the door?
2. Floor seepage – Tung Chung Case
   - How does water move from floor surface to the dripping point?
3. Ceiling scanning only—Sham Shui Po Case

Field Study of Seepage in Fanling Case

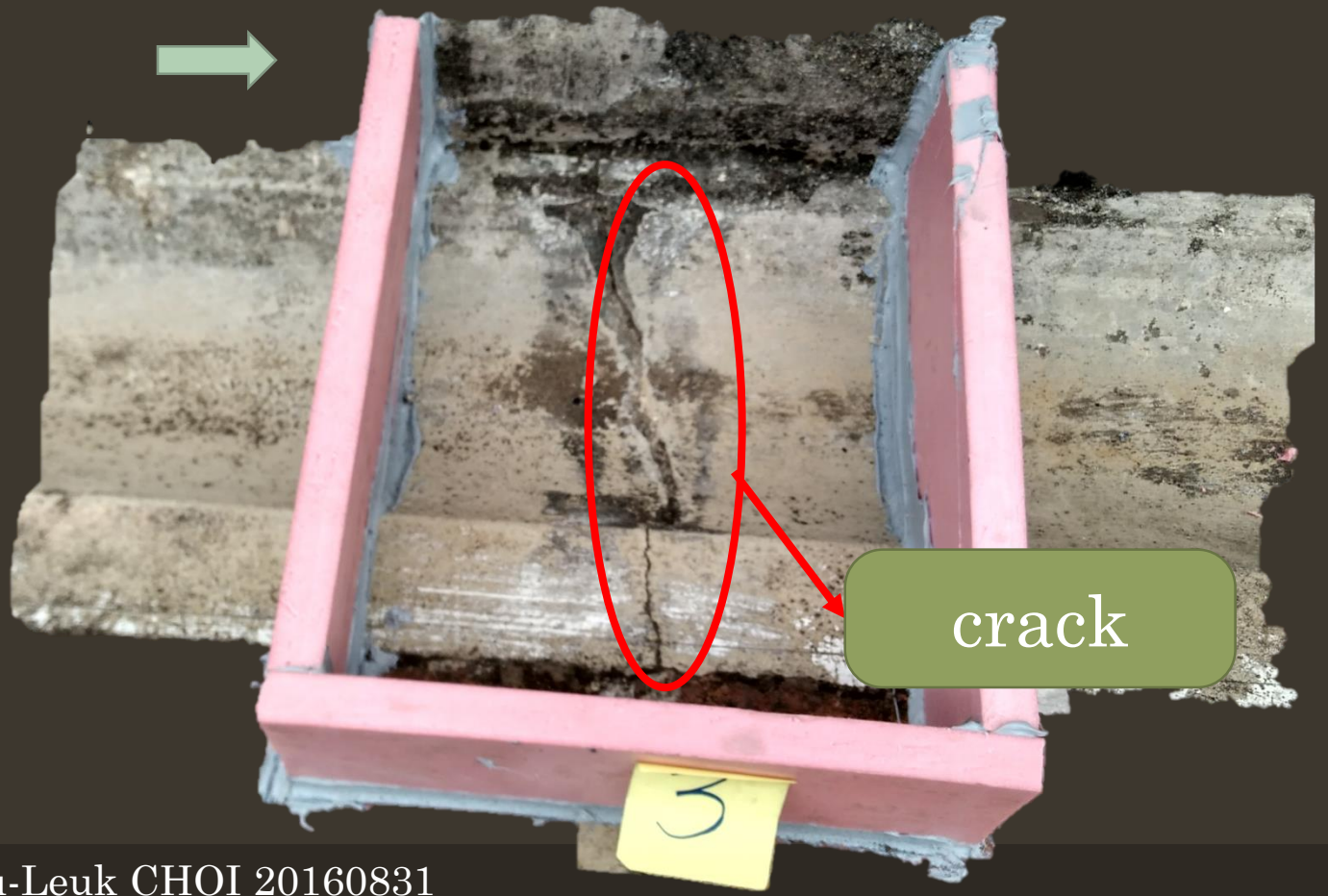
6 suspected Water Ingress Points were water sprayed on 17/4/2015

3. Crack 3 on roof channel not further tested.



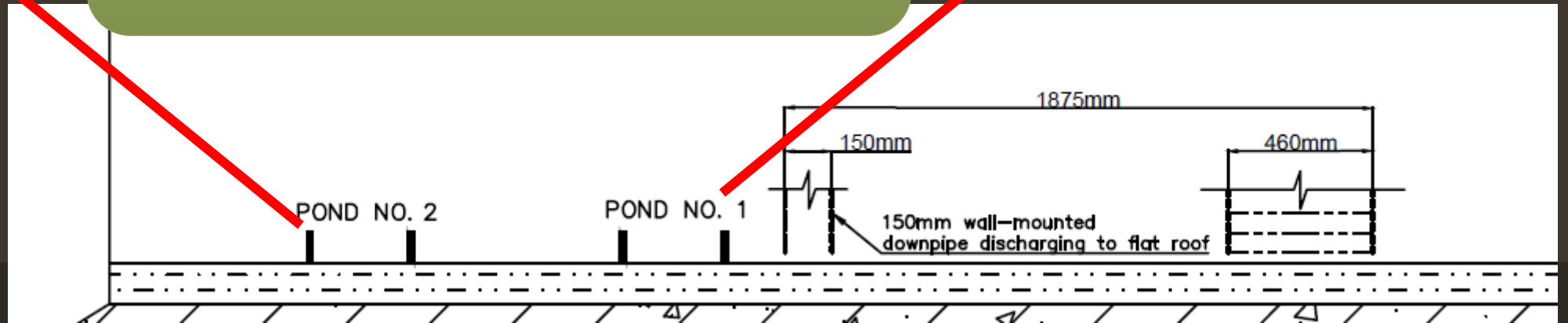
3 cracks observed in roof channel

- Ponding tests to check leakage by measuring change in water level
- Result : Pond 3 had no leakage



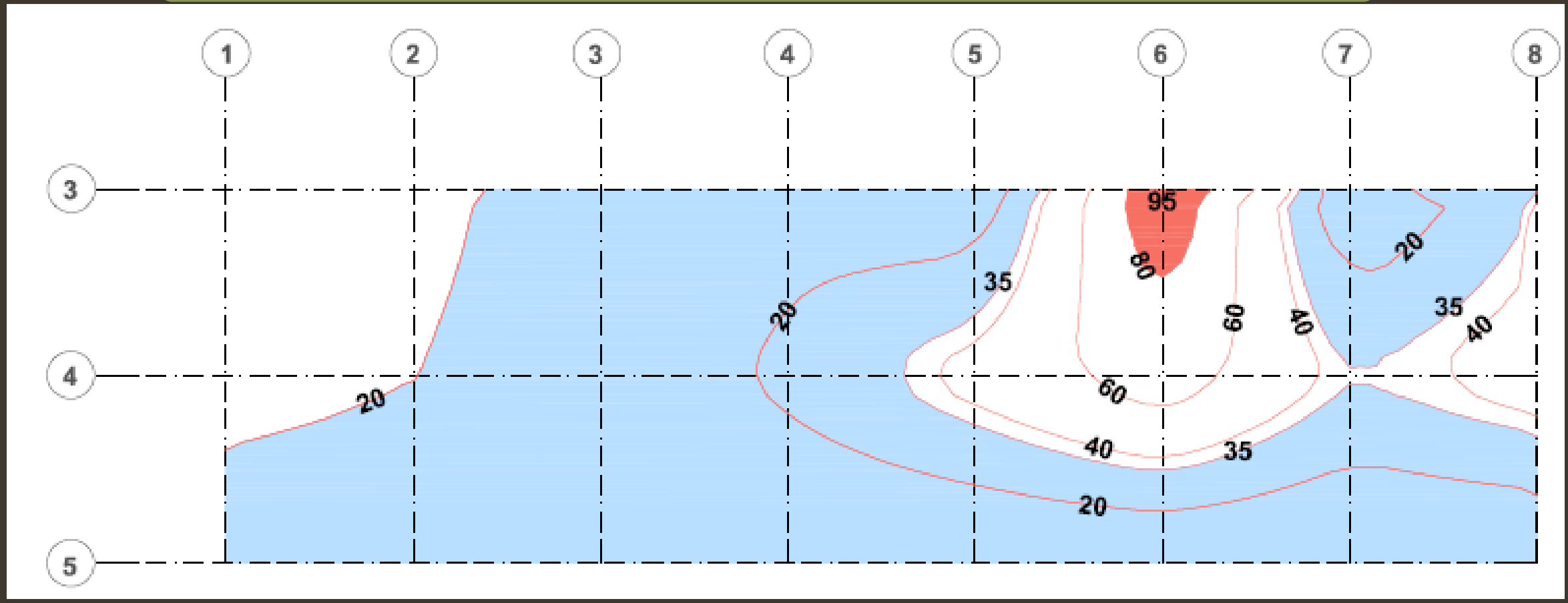
Remaining 2 cracks at Ponds 1 and 2 are inter-connected

Water leakage was observed between two ponds after 10 minutes from start of both ponds



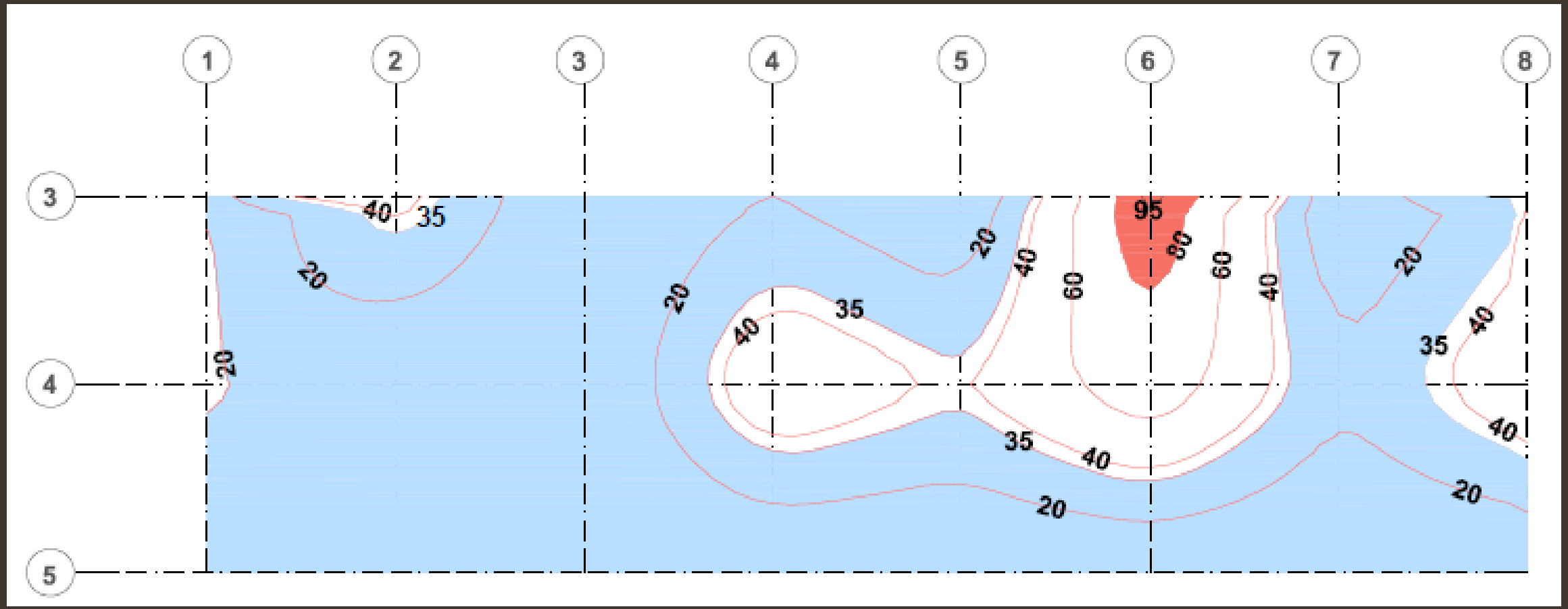
Field Study of Seepage in Fanling Case : Water spray-Scanning test0

Moisture Contours Map at T_2 = 11:41 on 17/4/2015



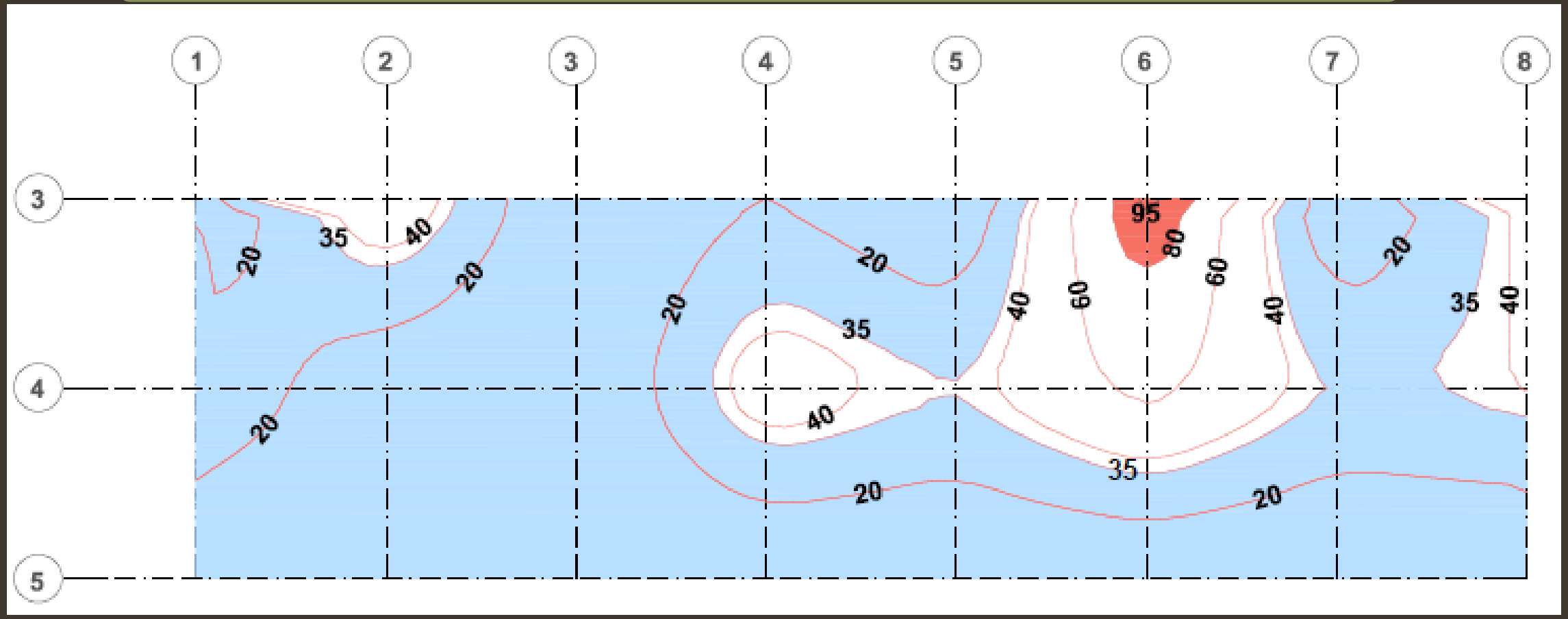
Field Study of Seepage in Fanling Case : Water spray-Scanning test

Moisture Contours Map at T_5 = 12:26 on 17/4/2015



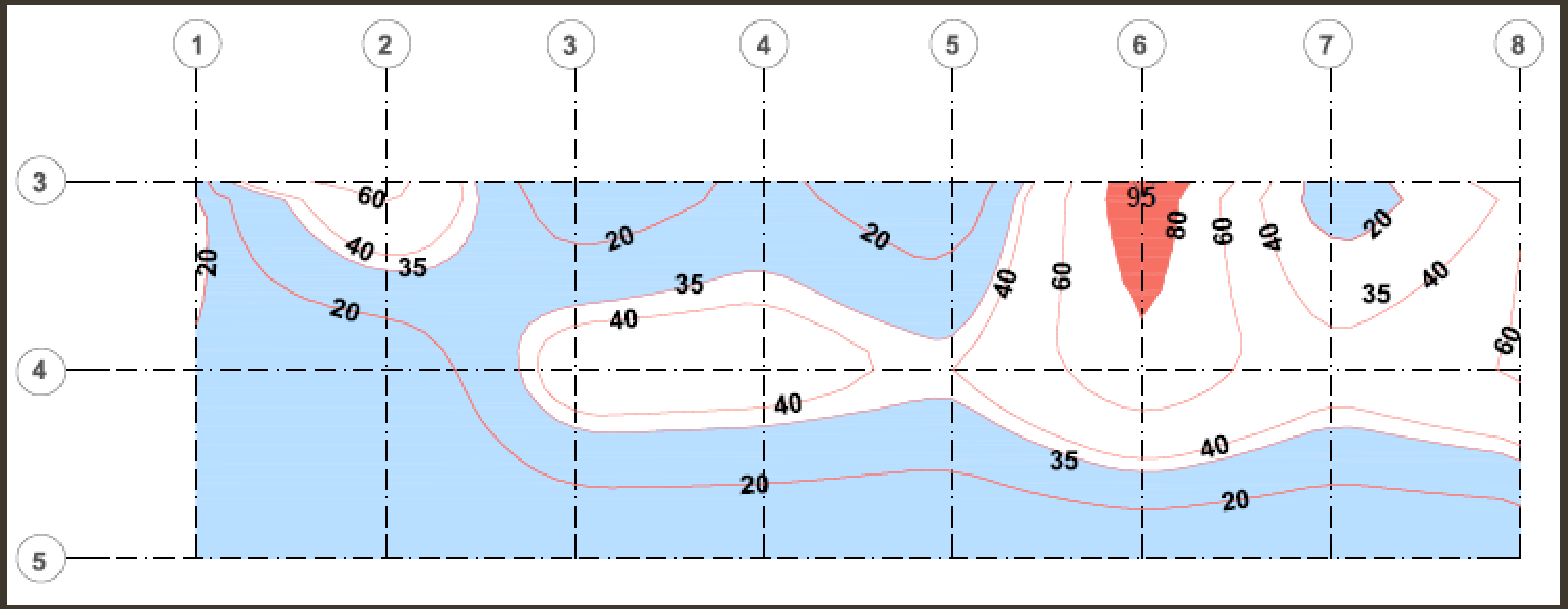
Field Study of Seepage in Fanling Case : Water spray-Scanning test

Moisture Contours Map at T_7 = 12:56 on 17/4/2015



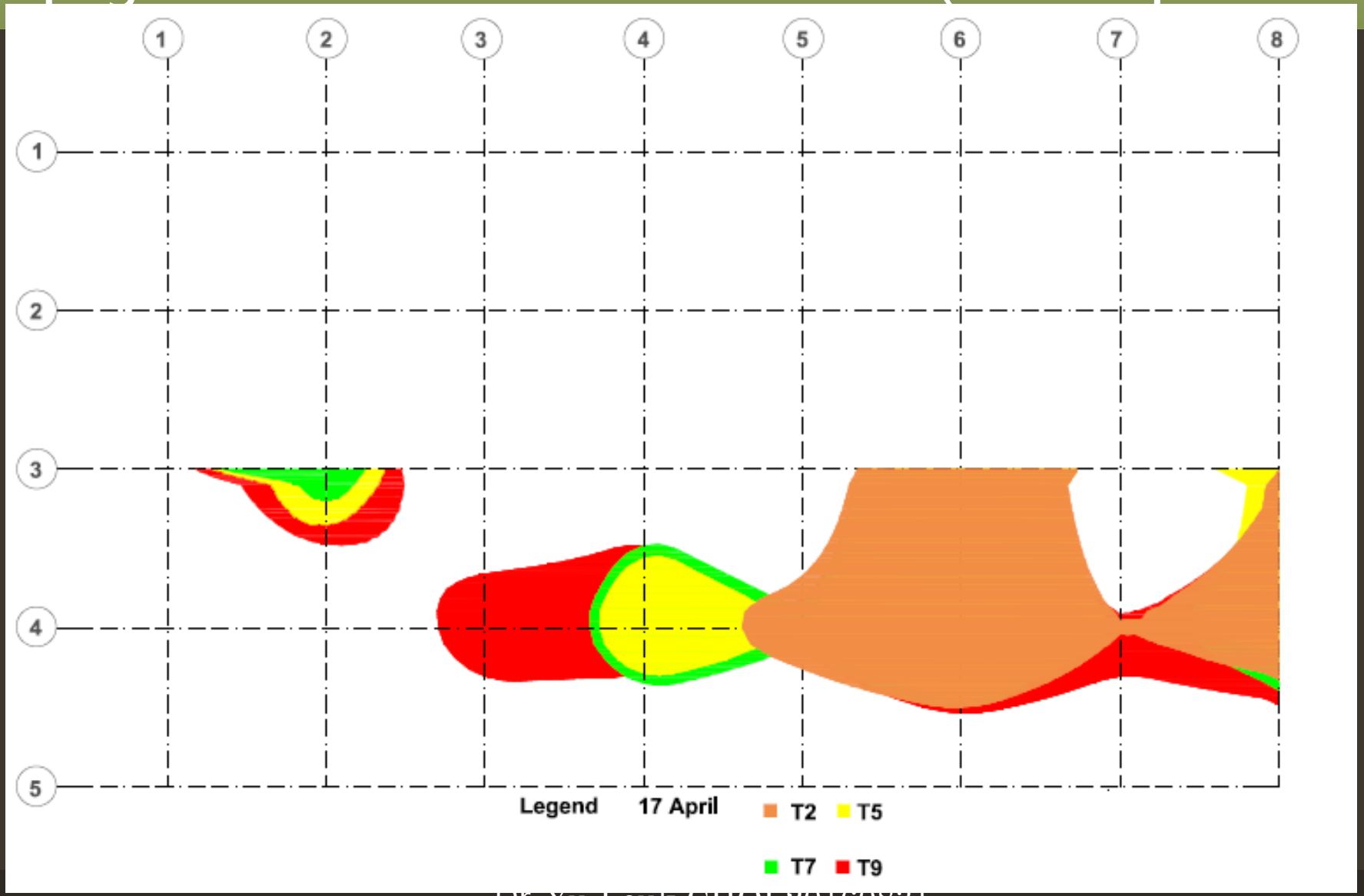
Field Study of Seepage in Fanling Case : Water spray-Scanning test

Moisture Contours Map at T_9 = 13:26 on 17/4/2015



Field Study of Seepage in Fanling Case

Propagation of 35-contours with time (on 17 April 2015)



Part of Wall remained dry

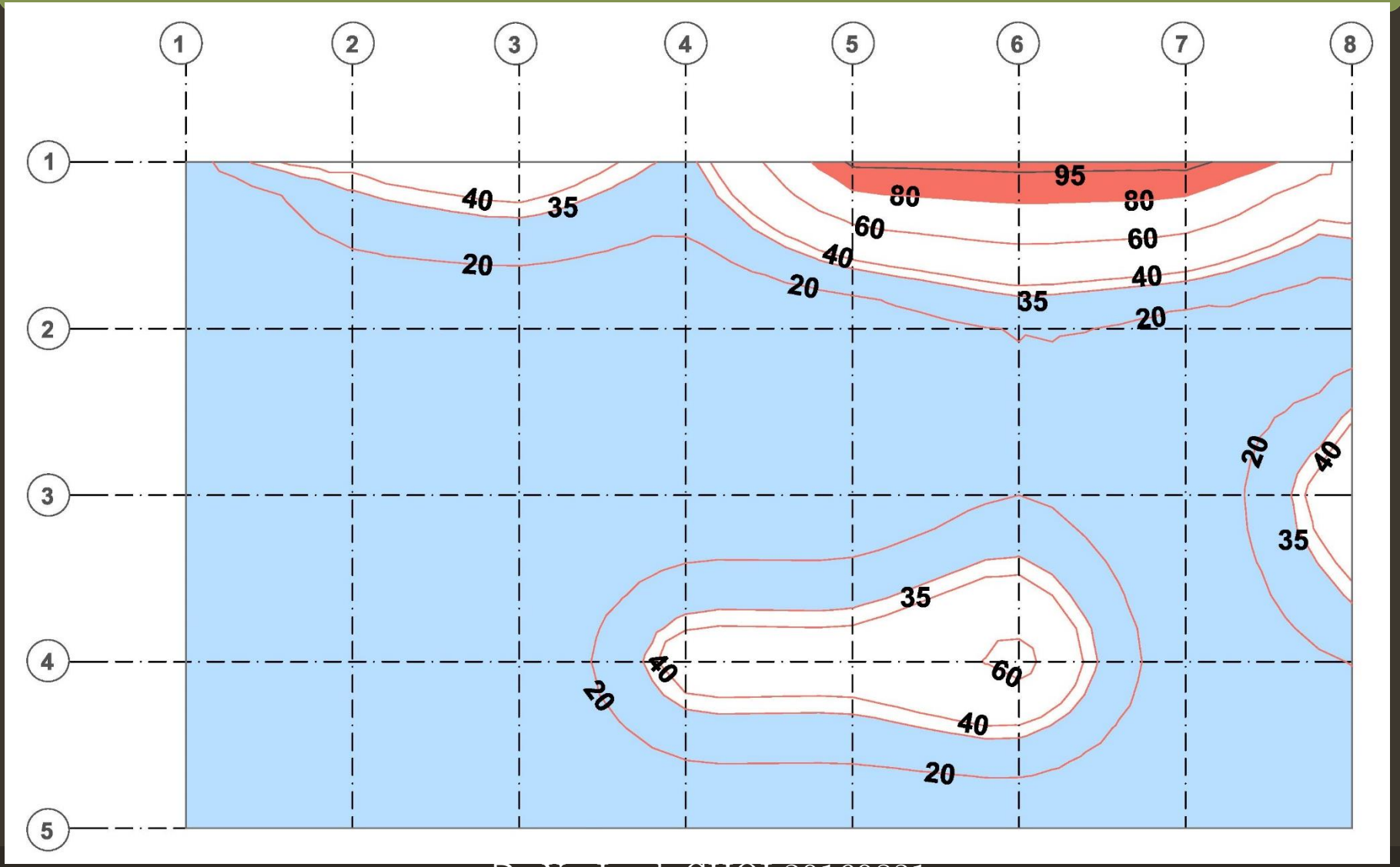
Horizontal flow at Y4 level

Fanling Study up to 17/4/2015
Hydraulic Analysis of moisture contour maps

- 3 separate streams
- Rate of descent of 80 contour ~ 1 cm/h ~ 2.8 x 10^-3 mm/s
- Compare with concrete permeability of 10^-5. Hence flow turns horizontal above RC beam.
- Time to descend from Y1 to Y3 ~ 1 m / (1cm/h) ~ 100 h =4.2 days. Hence flow below Y3 on 17/4/2015 is from wall infiltration only.
- Validated by subsequent ponding-scanning test on 16/6/2015

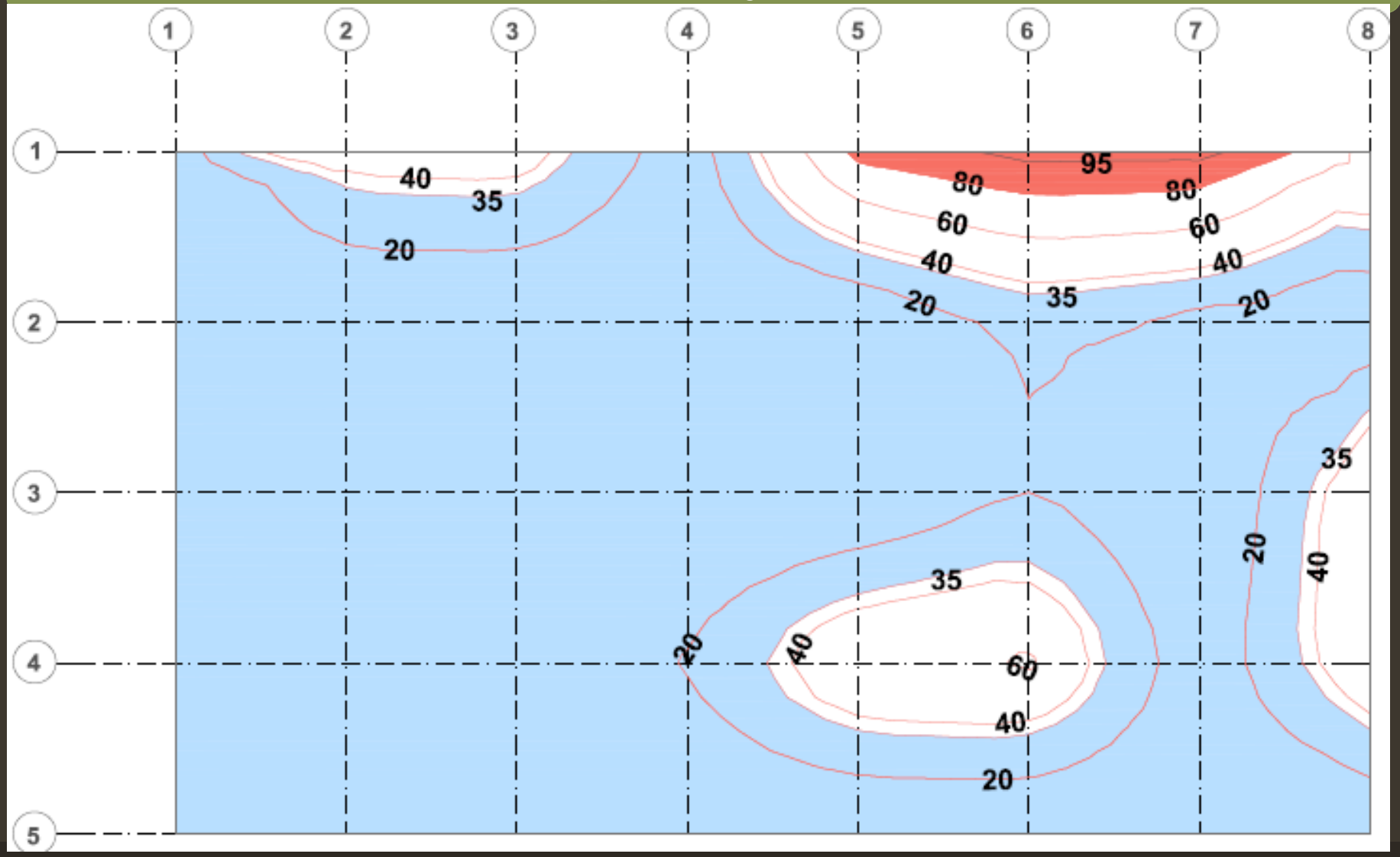
Field Study of Seepage in Fanling Case : Ponding-scanning Test

Moisture Contours Map at T_3 = 13:04 on 16/6/2015



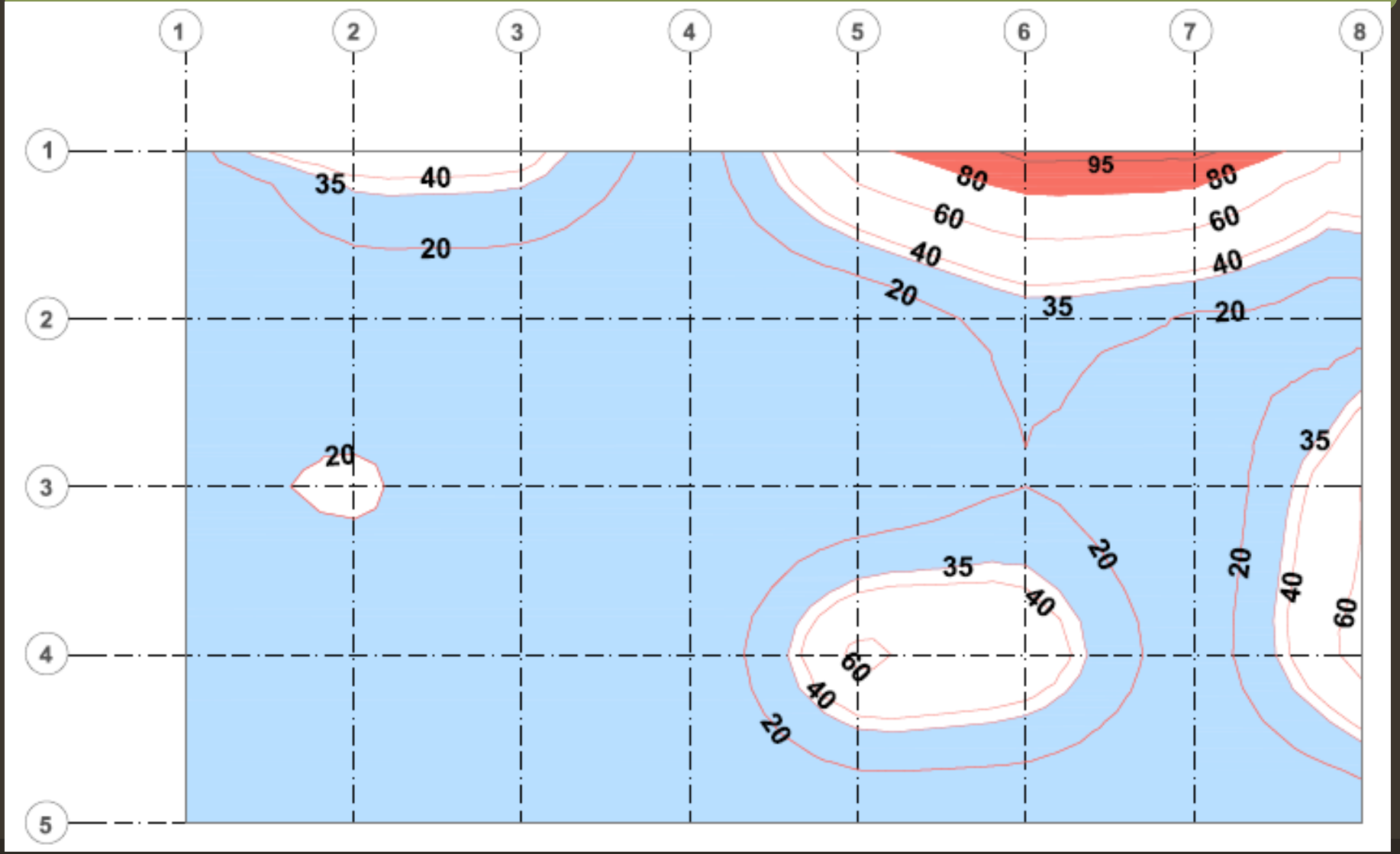
Field Study of Seepage in Fanling Case: Ponding-scanning Test

Moisture Contours Map at T_6 = 13:49 on 16/6/2015



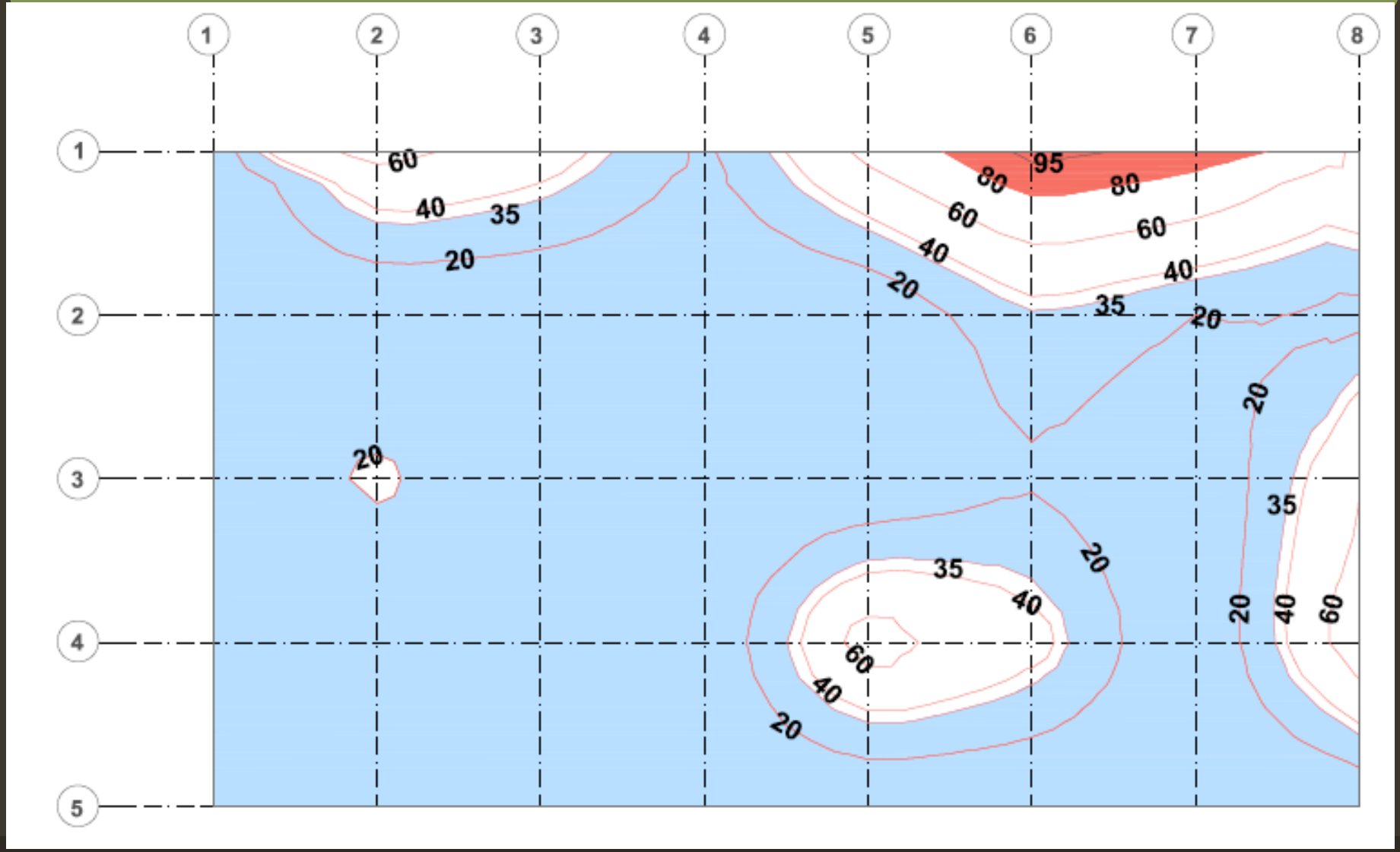
Field Study of Seepage in Fanling Case: Ponding-scanning Test

Moisture Contours Map at T_8 = 14:19 on 16/6/2015



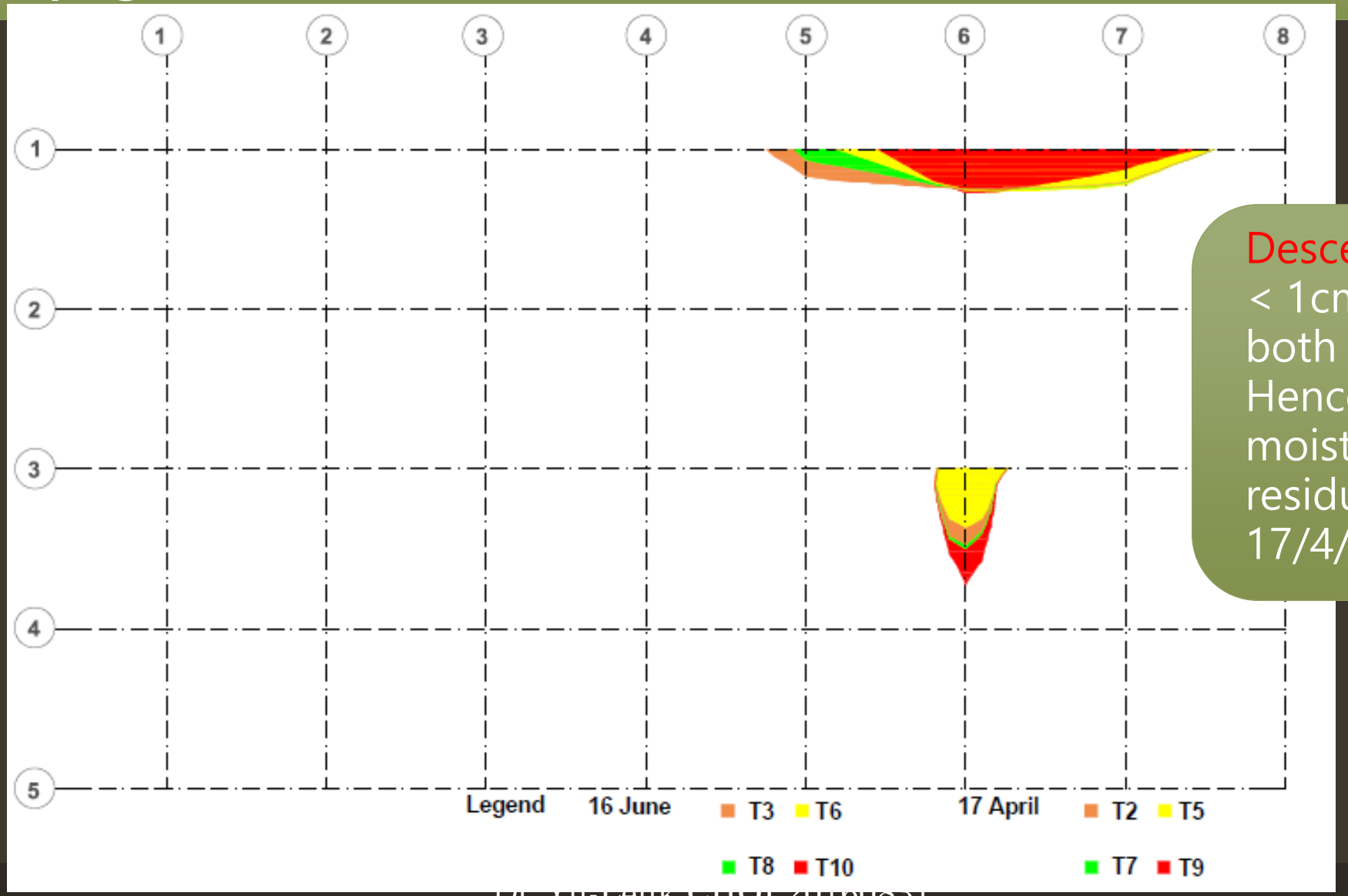
Field Study of Seepage in Fanling Case: Ponding-scanning Test

Moisture Contours Map at T_{10} = 14:49 on 16/6/2015



Field Study of Seepage in Fanling Case

Propagation of 80-contours with time (from both tests)

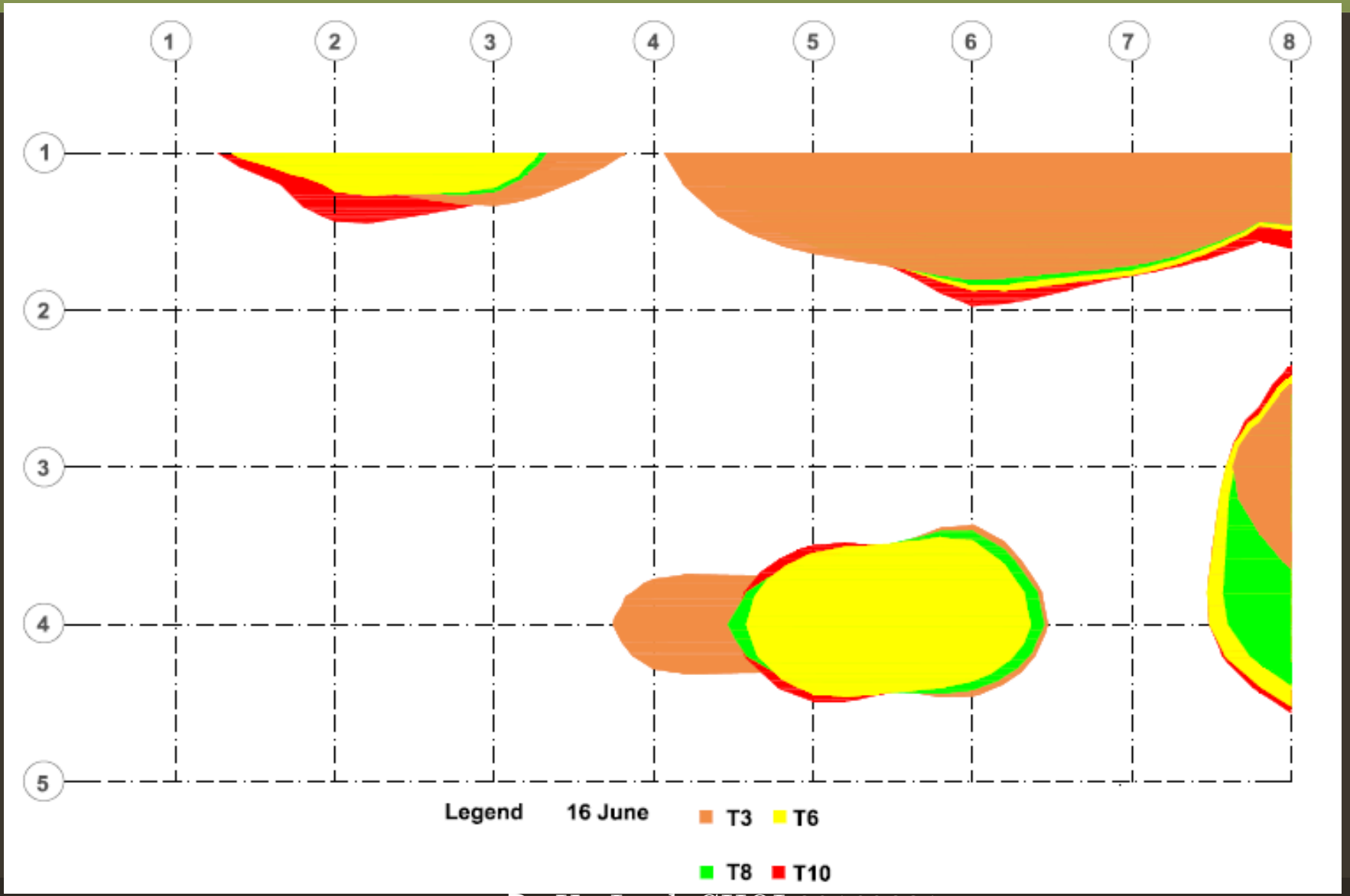


Descending Flow < 1cm /hr, both dates. Hence, lower moisture patch is residual from 17/4/15

Field Study of Seepage in Fanling Case

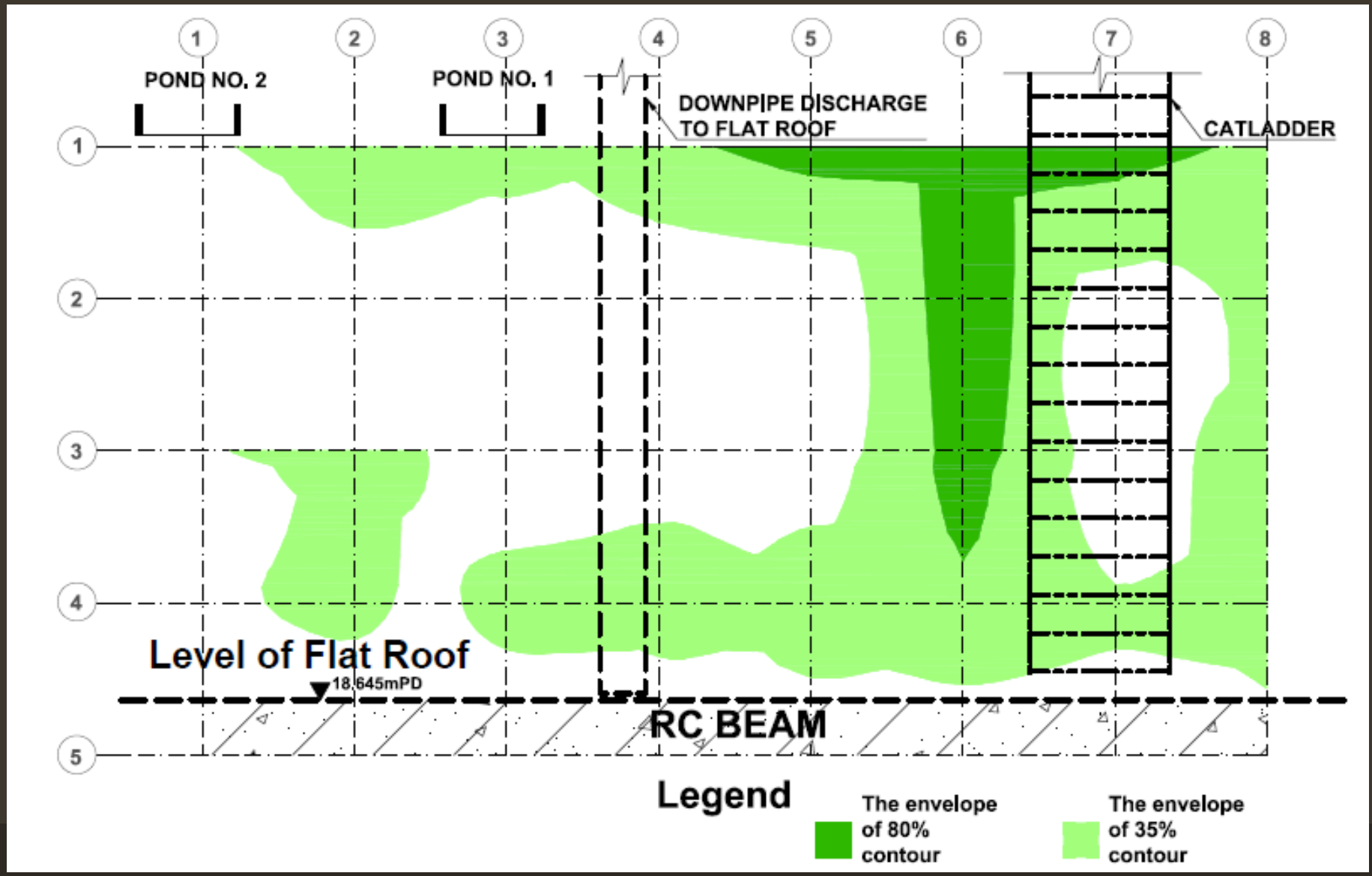
Propagation of 35-contours with time (on 16 June 2015)

Part of Wall remained dry.



Field Study of Seepage in Fanling Case

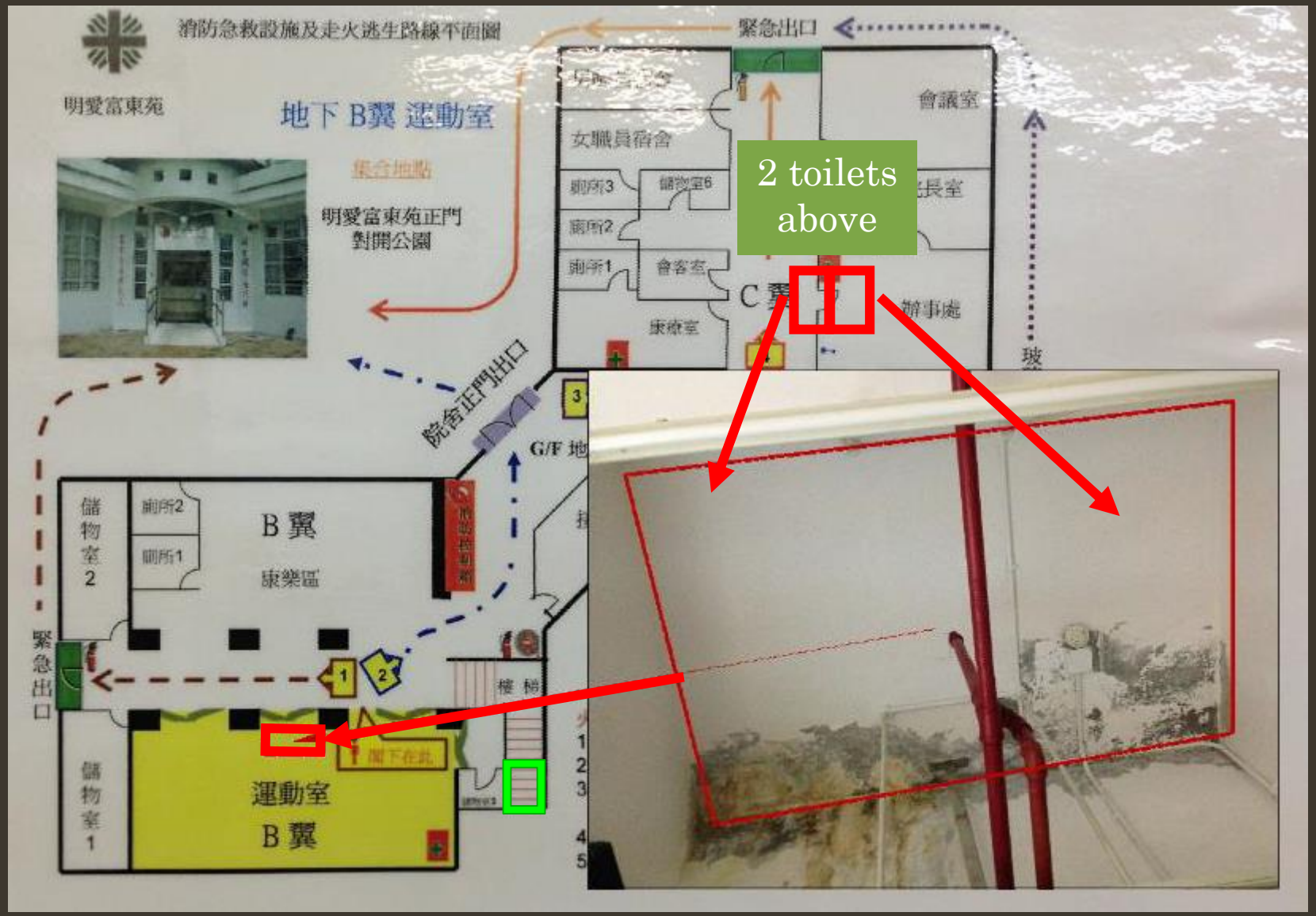
Flow Field in Wall : reflection of permeability



Conclusion of Fanling Study

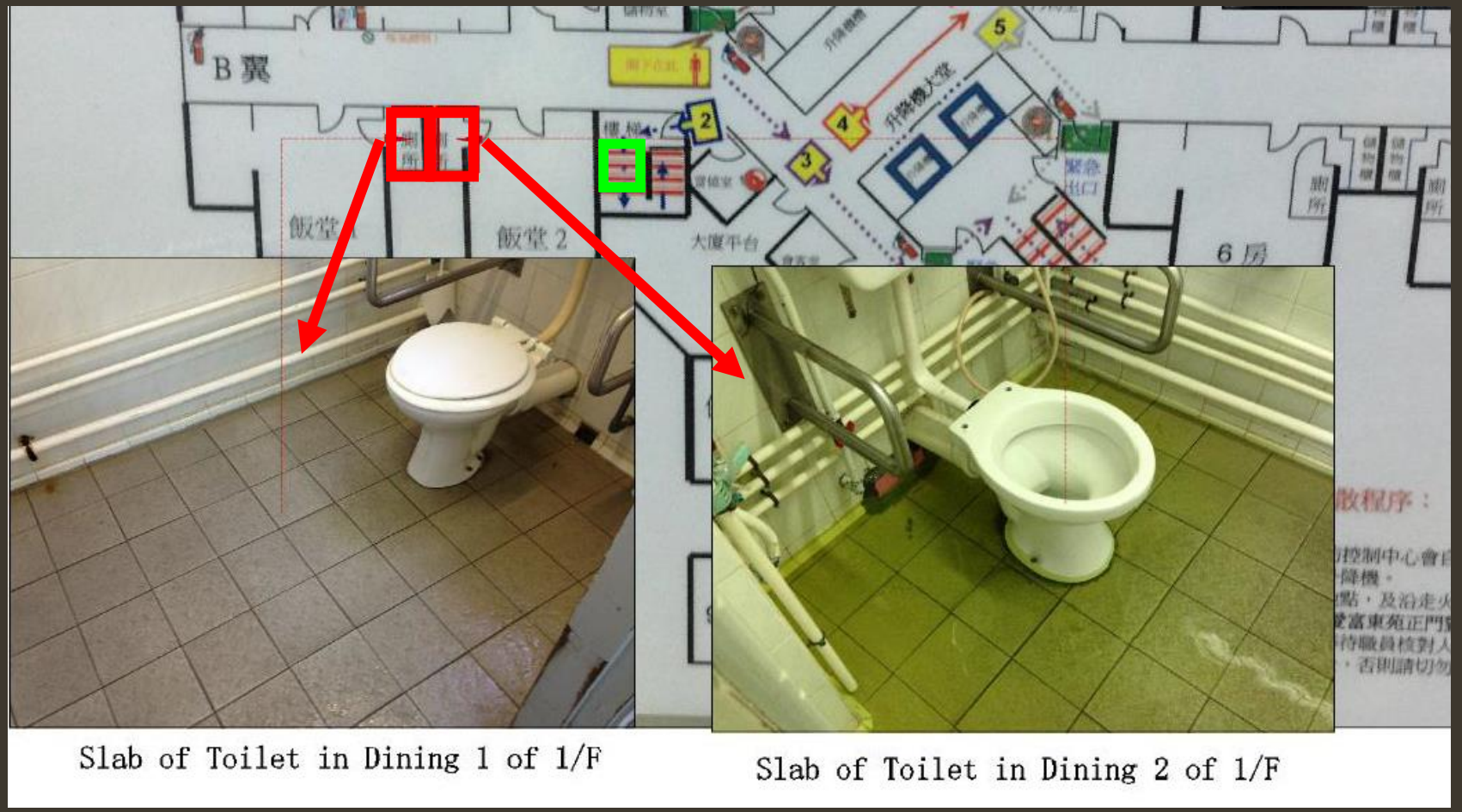
1. RC is effectively impermeable
2. Wall dampness is caused by infiltration from the external face as well as from cracks on the roof channel.
3. Corollary : Surface water-proofing layer is an effective means of preventing seepage in brick wall.

Field Study of Seepage in Tung Chung Cases



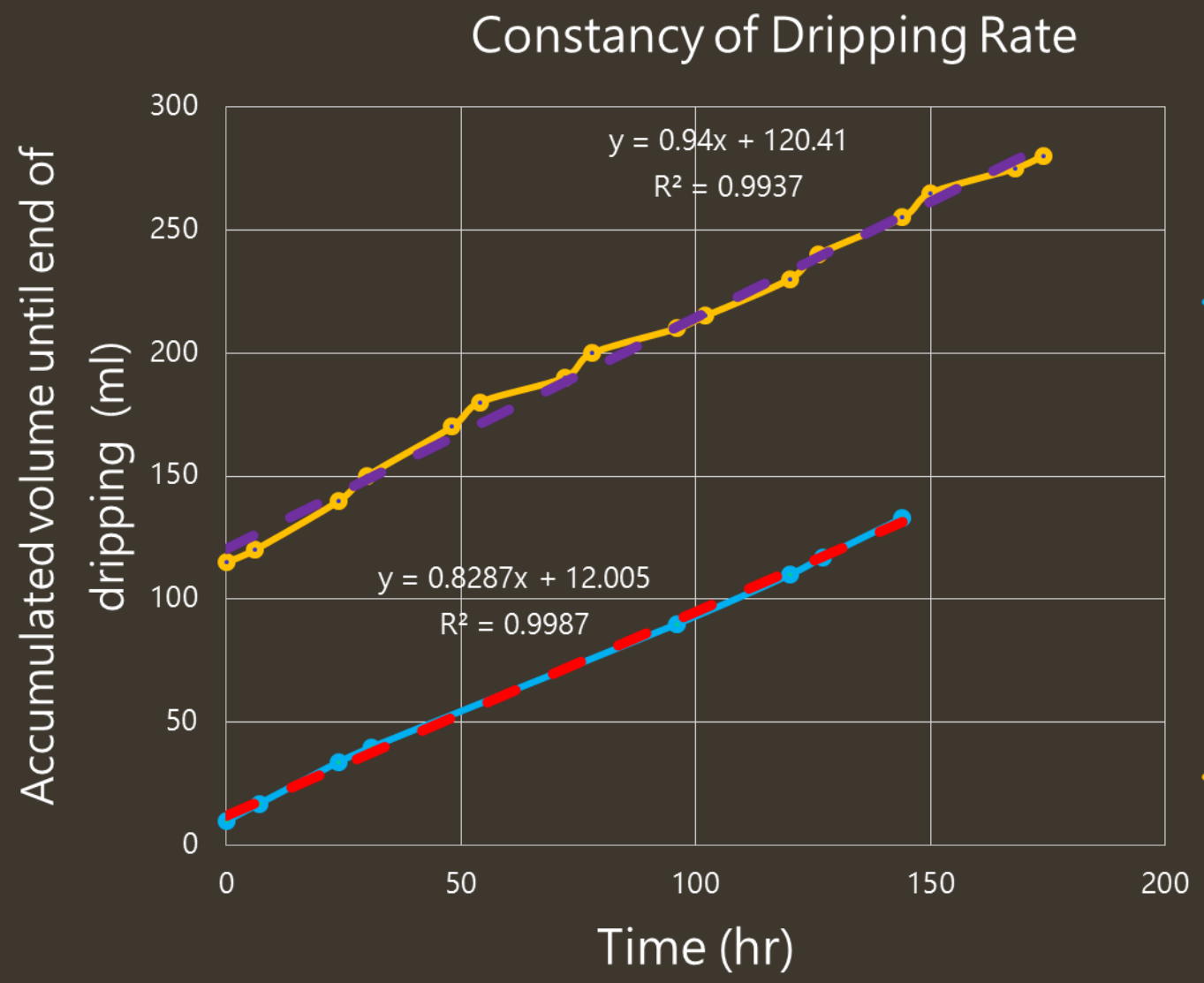
Ground Floor Plan

Field Study of Seepage in Tung Chung Cases



1st Floor Plan and 2 toilets

Field Study of Seepage in Tung Chung Cases



Vol. of dripping at PTR measured from

29/1/15-4/2/15

Dripping rate 19.9ml/day ($R^2 = 0.999$)

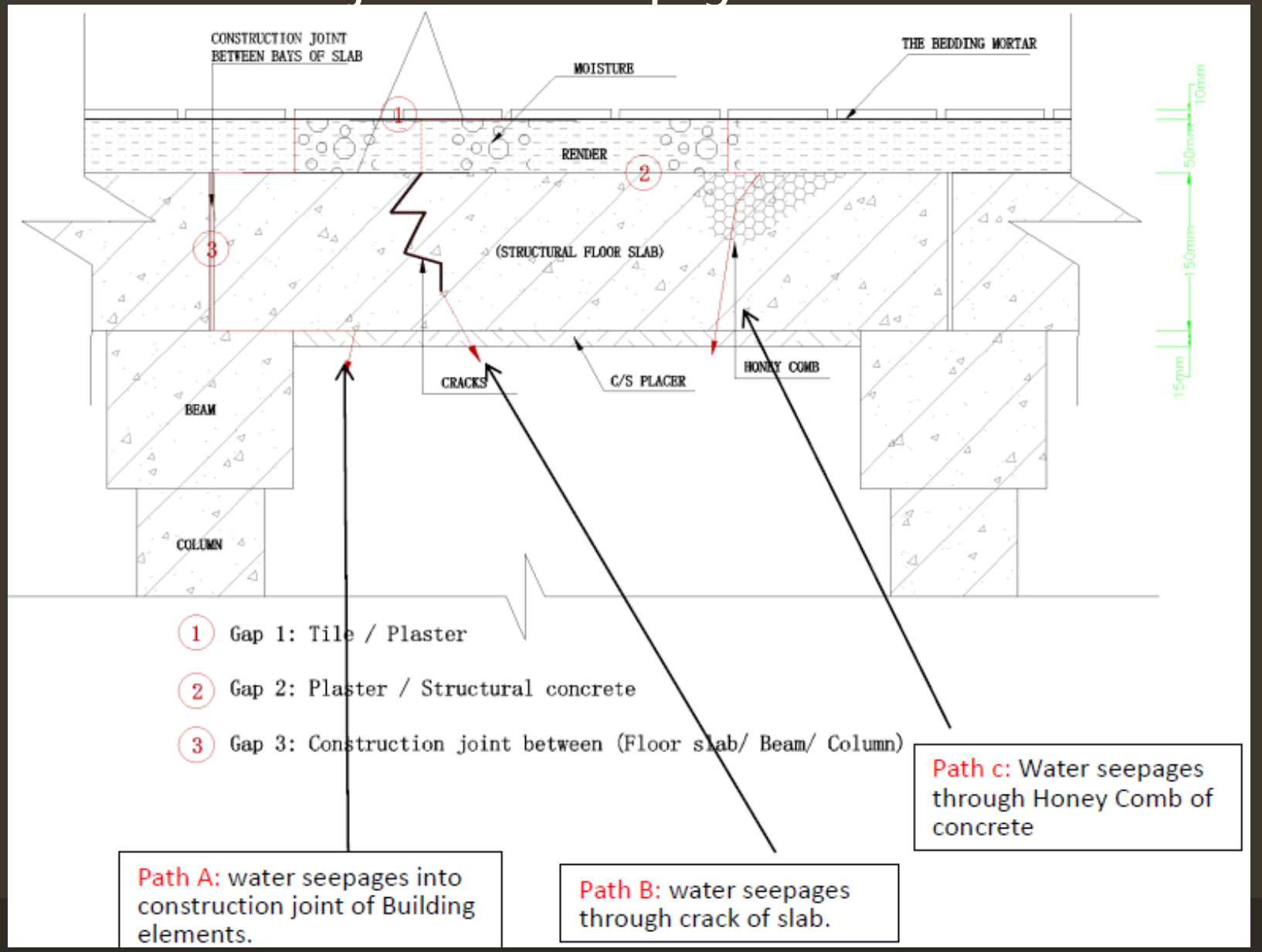
Vol. of dripping at PTR measured from

3/4/15-10/4/15

Dripping rate 19.74ml/day ($R^2 = 0.994$)

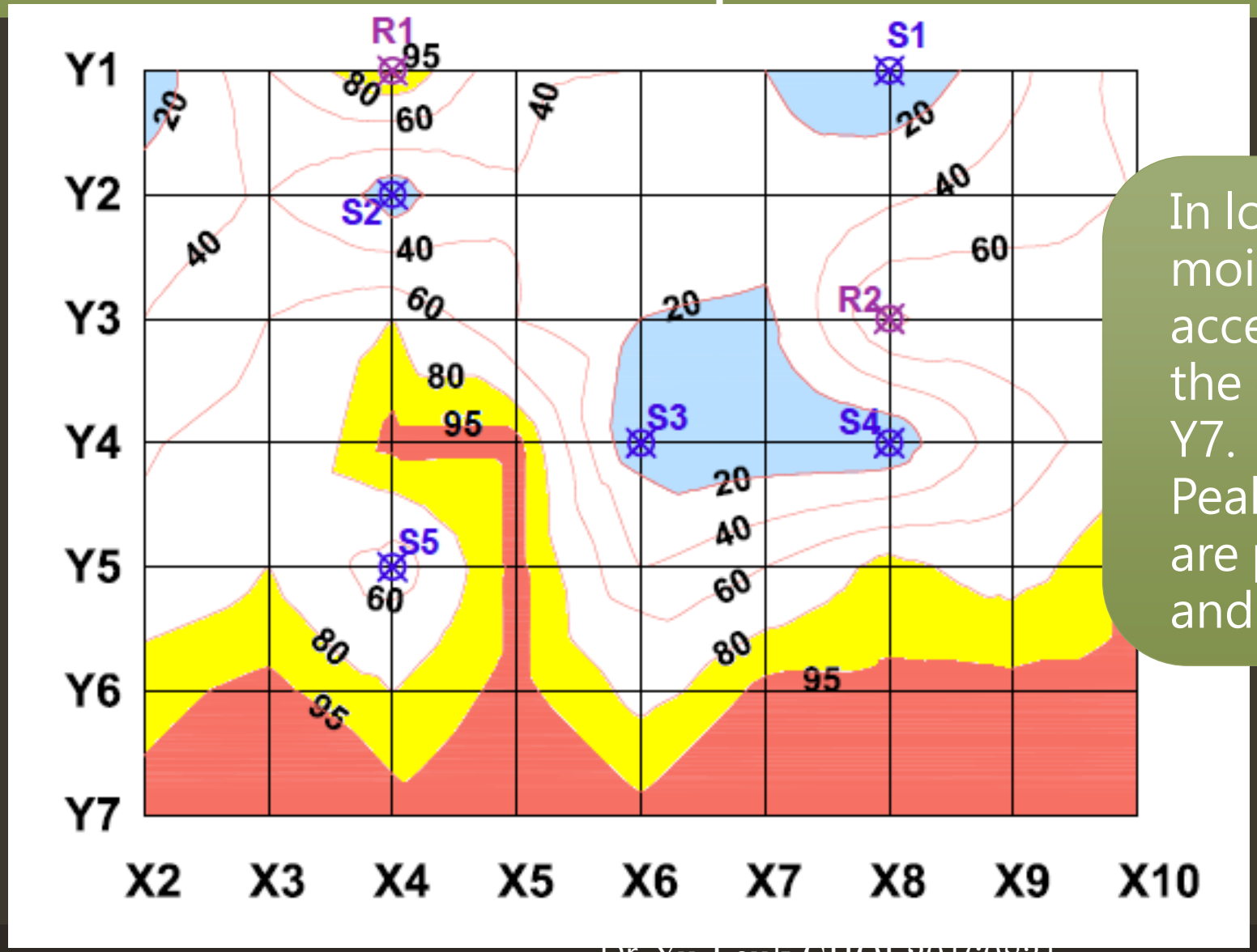
Field Study of Seepage in Tung Chung Cases

Intuitive Conjecture of Seepage Paths in Floor Slab



Field Study of Seepage in Tung Chung Case

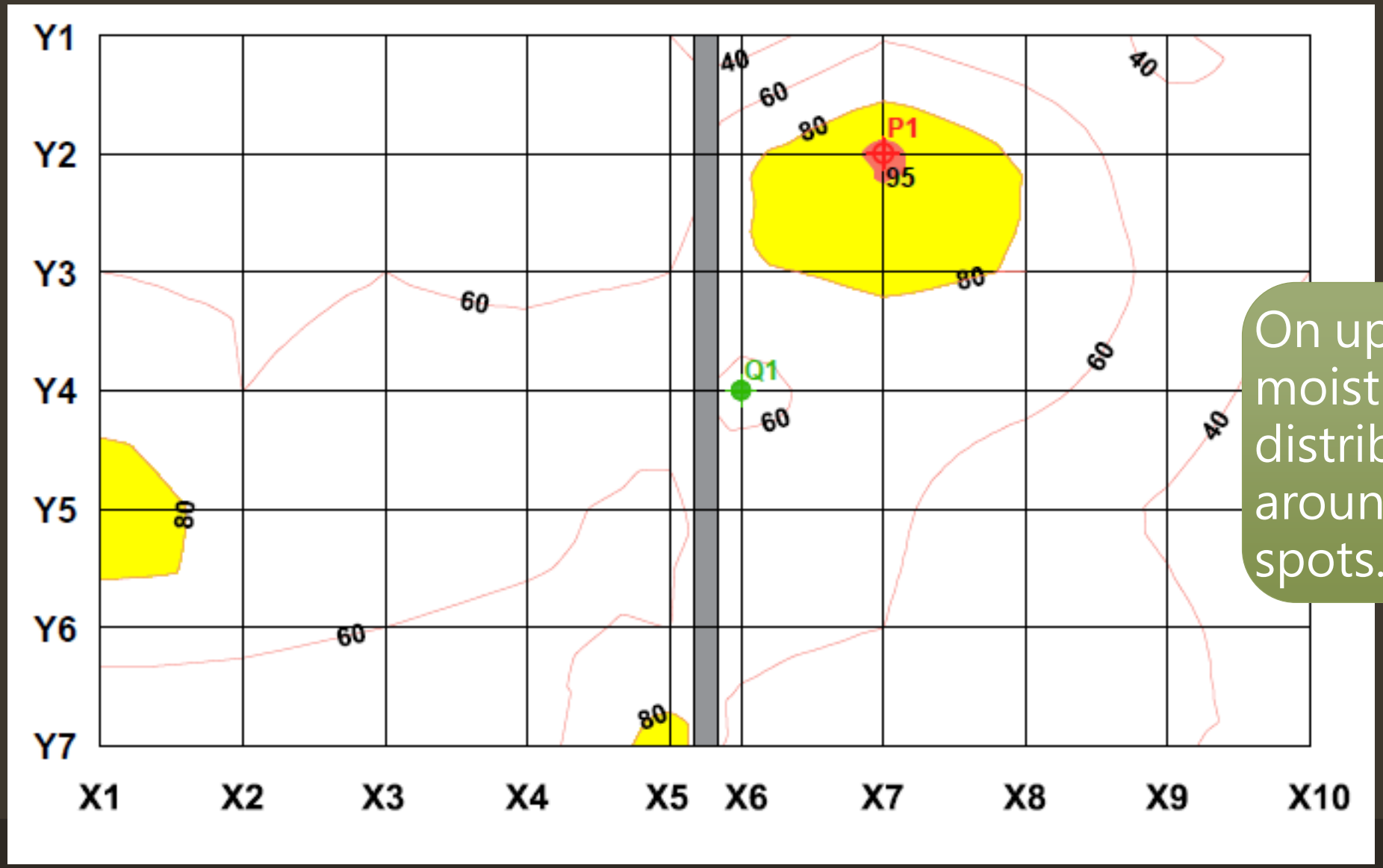
Moisture Contours Map for PT Room on 17/3/2015



In lower side, moisture is accentuated along the dampest line Y7.
Peaks and troughs are possible inflow and outflow points

Field Study of Seepage in Tung Chung Case

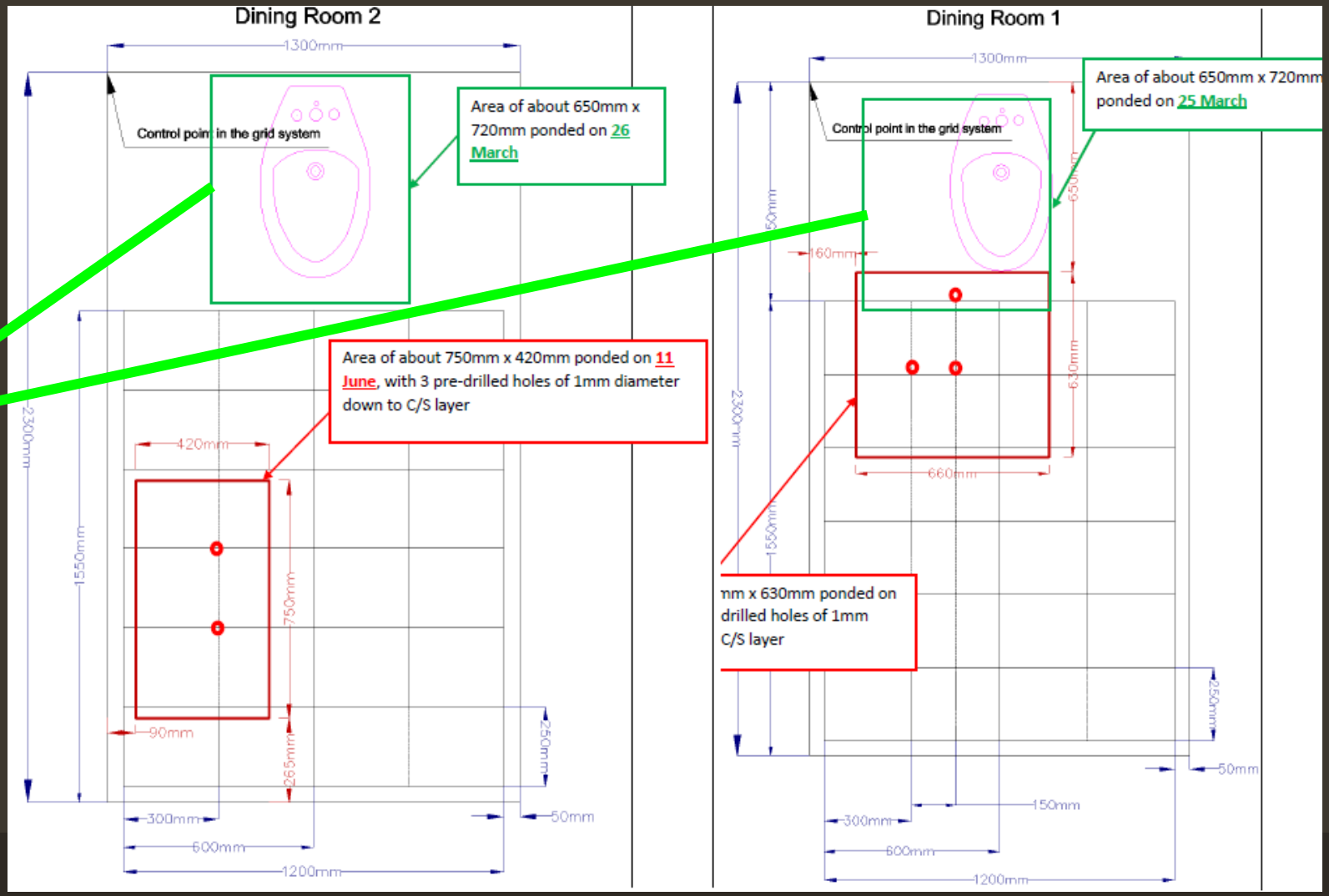
Moisture Contours Map for DR1 & DR2 on 17/3/2015



On upper side. moisture is distributed around 3 different spots.

Ponding setup in DR1 & DR2 on 25 & 26/3/2015 and on 11/6/2015

Pond area in DR1 & DR2 around toilet bowl



Ponding setup on 2/4/2015 in DR1 & DR2

Pond area in DR1 (whole slab)

Pond area in DR2 (whole slab)

Observed Time of First Water Droplet in the 3 Ponding Tests

Date	25/3/2015	26/3/2015	2/4/2015
Pond Position	Around toilet bowl in DR1	Around toilet bowl in DR2	Whole slab of both DR1 & DR2
Pond Size	630mm x 520mm	650mm x 720mm	2300mmx1300mm
Ponding duration	1 hr	1.5 hrs	DR1: 2 hrs 38 mins DR2: 1 hr 22 mins
Time to 1st drop of Water dripping	45 mins after ponding	50 mins after ponding	20 mins after 1st ponding

Intriguing Results from 3 Conventional Ponding Tests in Tung Chung Case

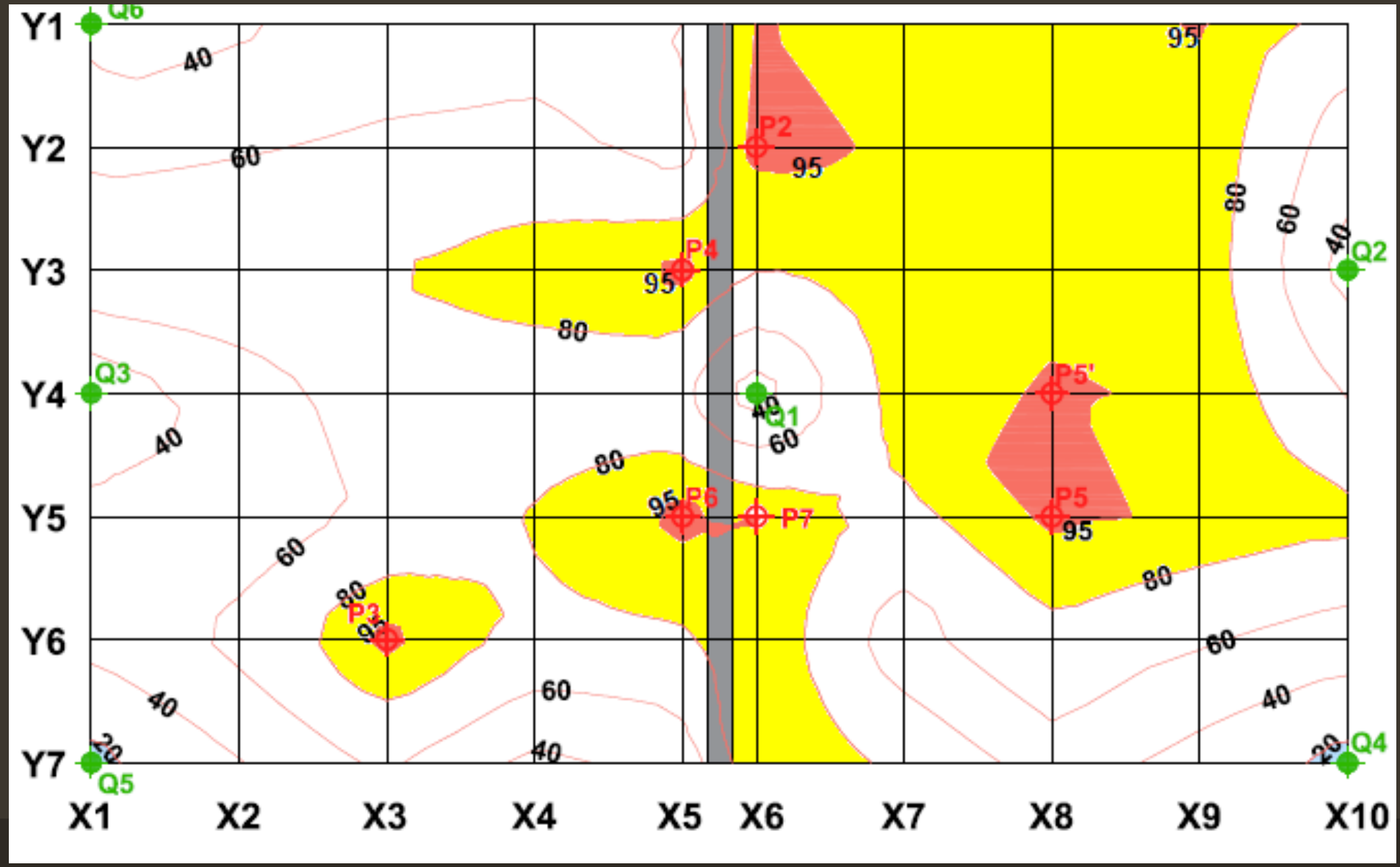
1. Constancy of dripping rate
2. Time to observable 1st water droplet varies from 50 minutes to 20 minutes in March & April 2015
3. **No** Water droplet was observable on 11 June 2016 after 2 hours of ponding

Tung Chung Study
Hydraulic Analysis

- Surface area of water table (WT) above dripping point >> cross-sectional area of dripping path. Hence 3-d inflow to dripping point. (Type 2 building seepage)
- Multiple paths of moisture flow to WT.
- Peaks and troughs in moisture contour map are potential inflow paths.
- Validated and amplified in subsequent ponding-scanning test on 11/6/2015.

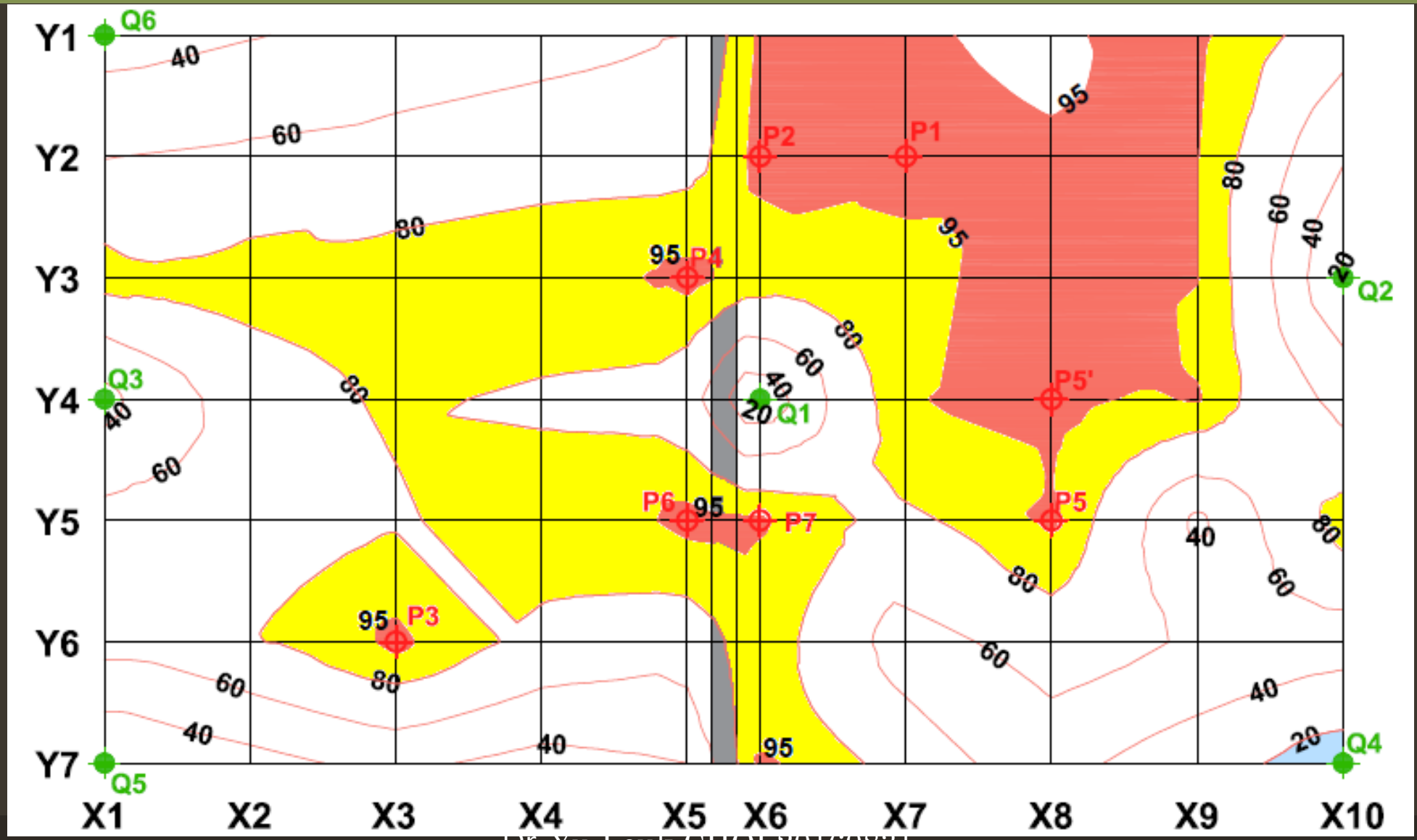
Field Study of Seepage in Tung Chung Case

Moisture Contours Map for T_0 = 8:00pm, DR1 & DR2,11/6/2015



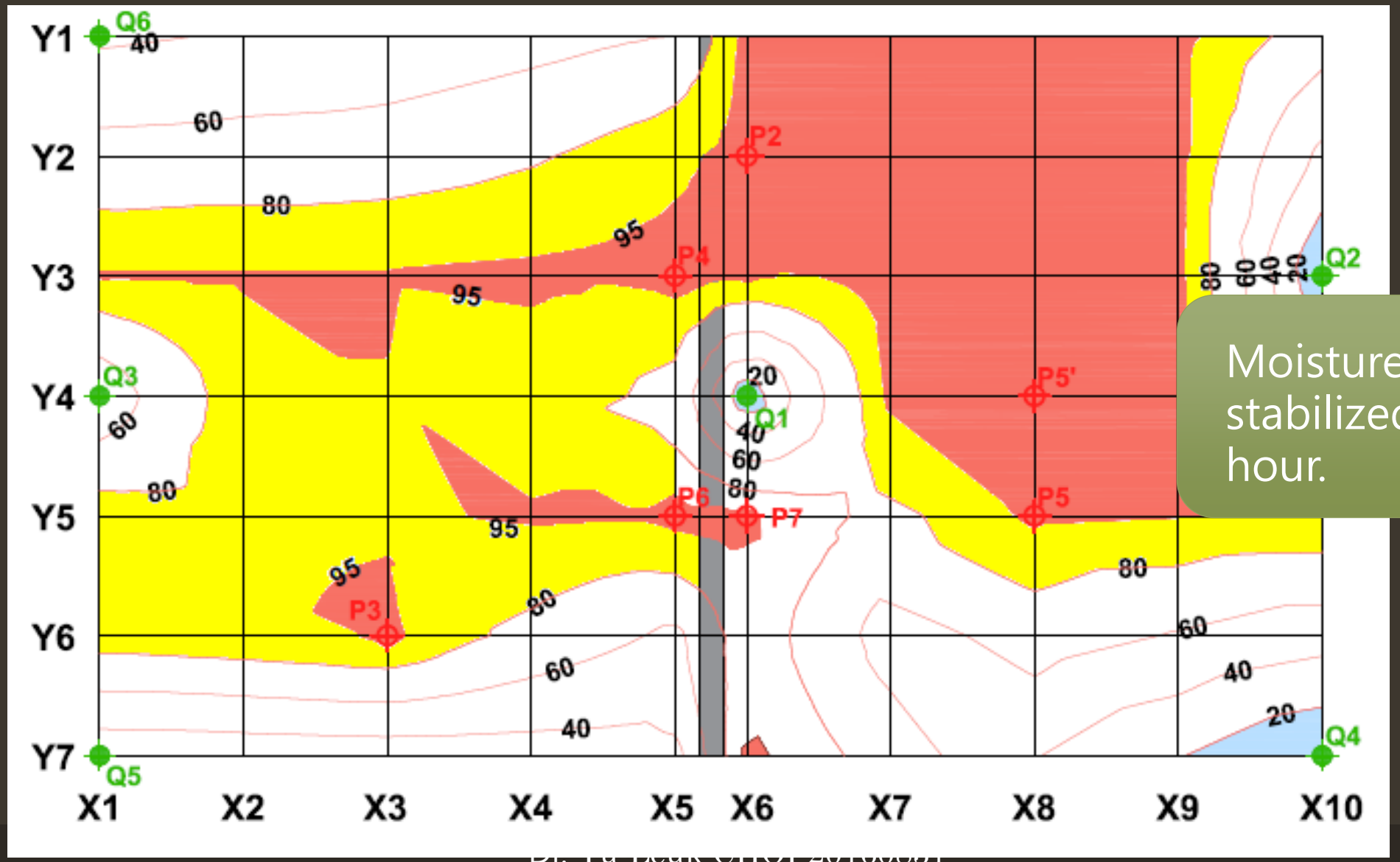
Field Study of Seepage in Tung Chung Case

Moisture Contours Map for T_1 = 8:30pm, DR1 & DR2,11/6/2015



Field Study of Seepage in Tung Chung Case

Moisture Contours Map for T_2 = 9:00pm, DR1 & DR2,11/6/2015

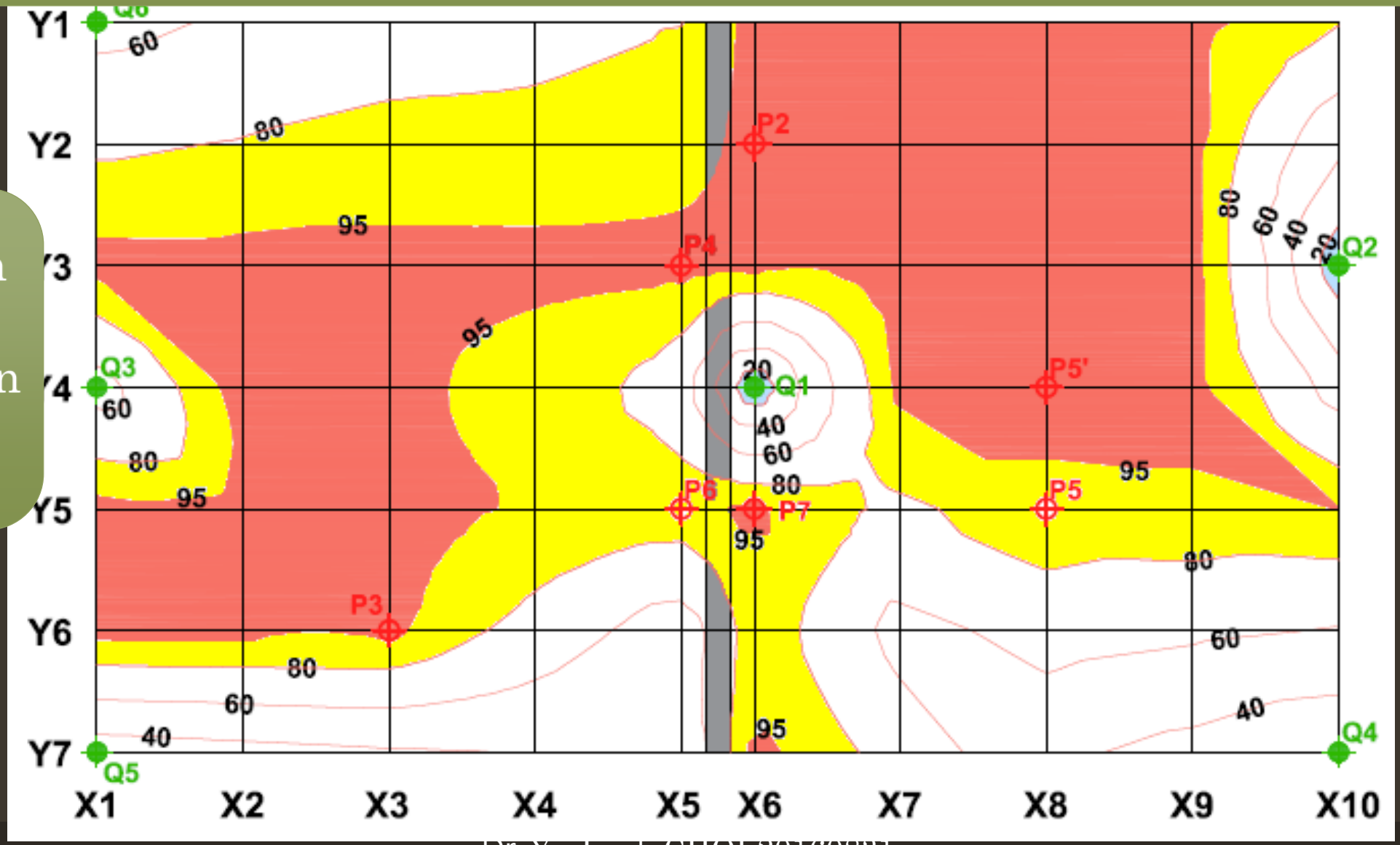


Moisture in DR1 stabilized in 1 hour.

Field Study of Seepage in Tung Chung Case

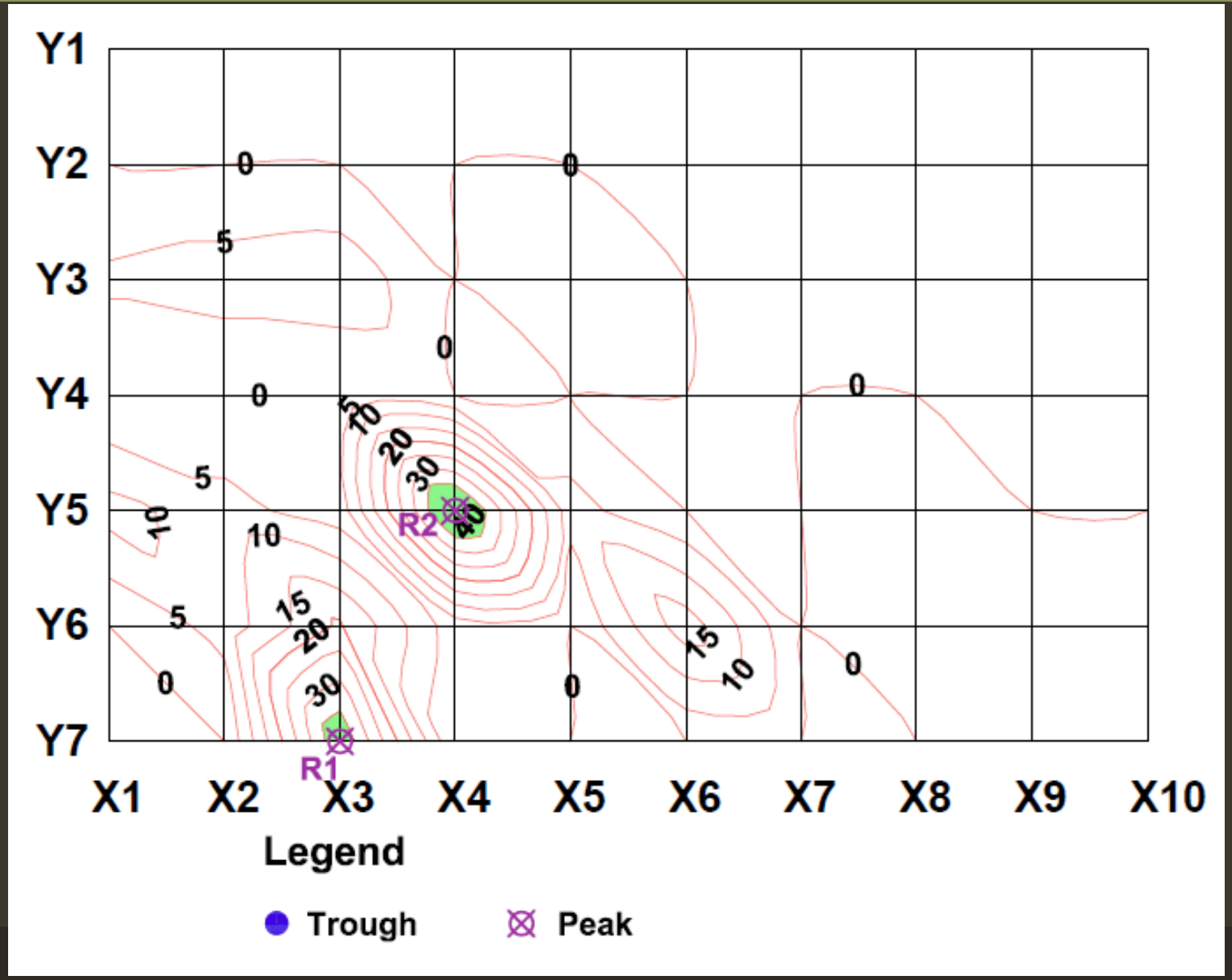
Moisture Contours Map for T_3 = 9:30pm, DR1 & DR2,11/6/2015

Moisture in DR2 stabilized in $1\frac{1}{2}$ hr



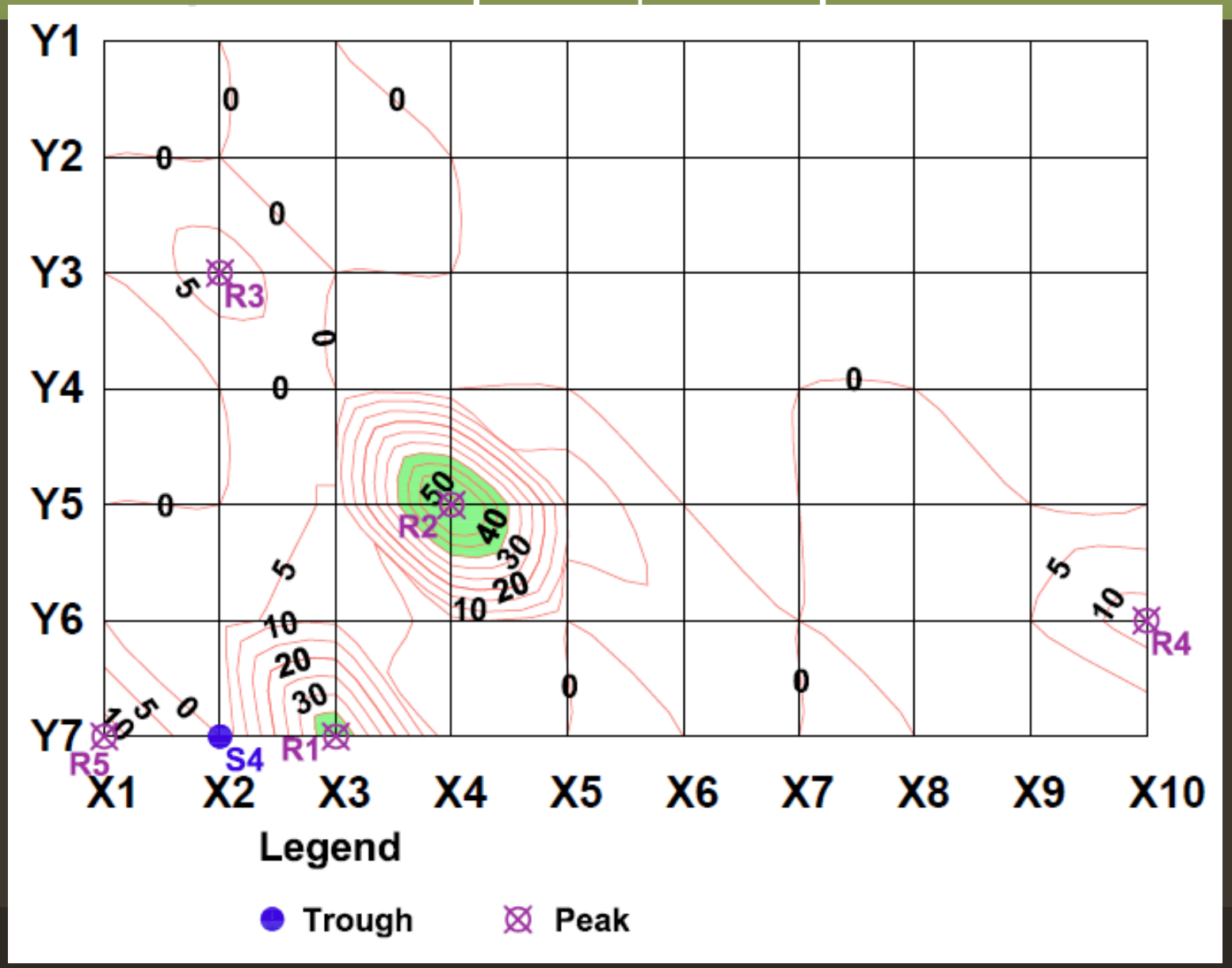
Field Study of Seepage in Tung Chung Case

Moisture Contours Map for T_0 = 8:00pm, PT Room,11/6/2015



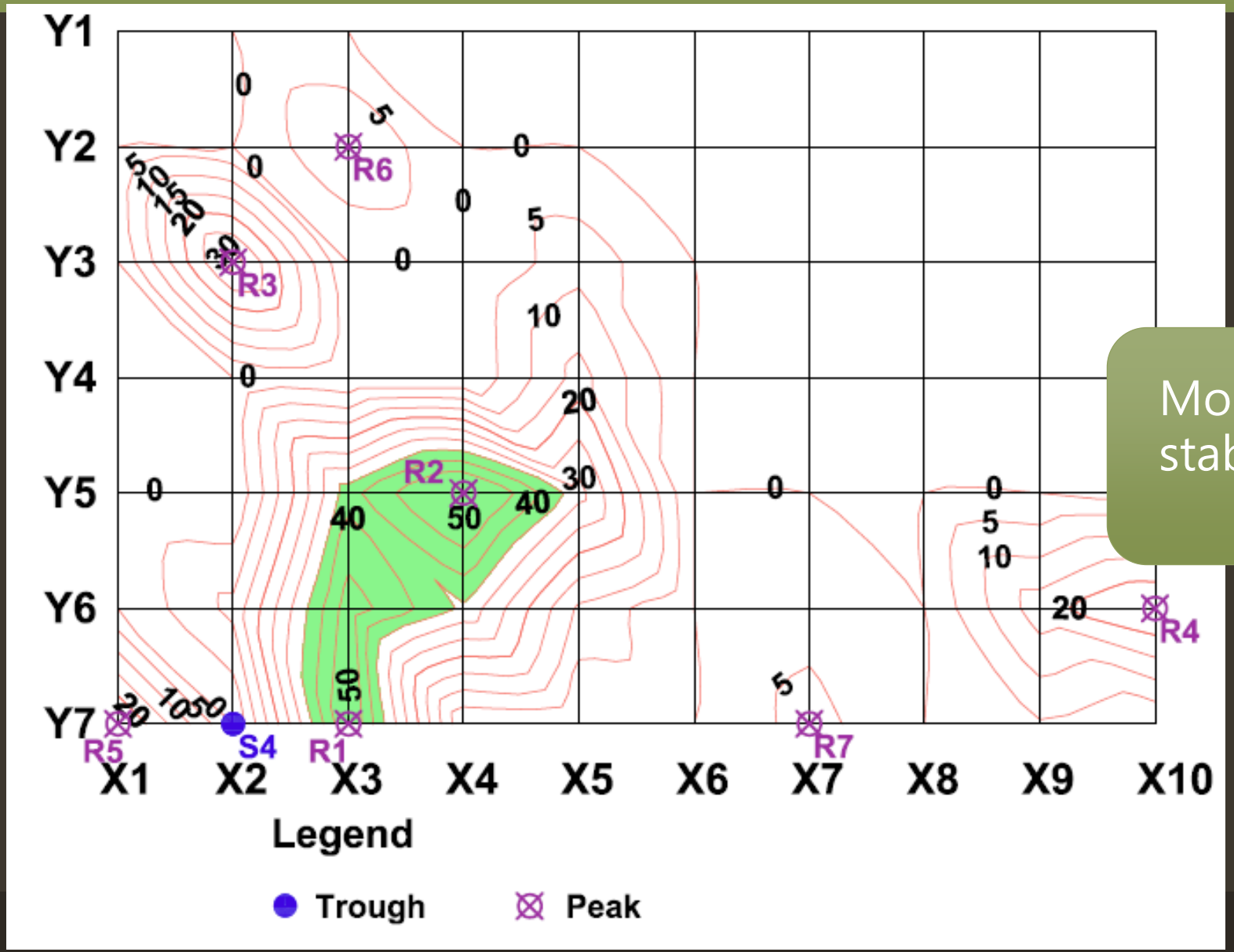
Field Study of Seepage in Tung Chung Case

Moisture Contours Map for T_1 = 8:30pm, PT oom,11/6/2015



Field Study of Seepage in Tung Chung Case

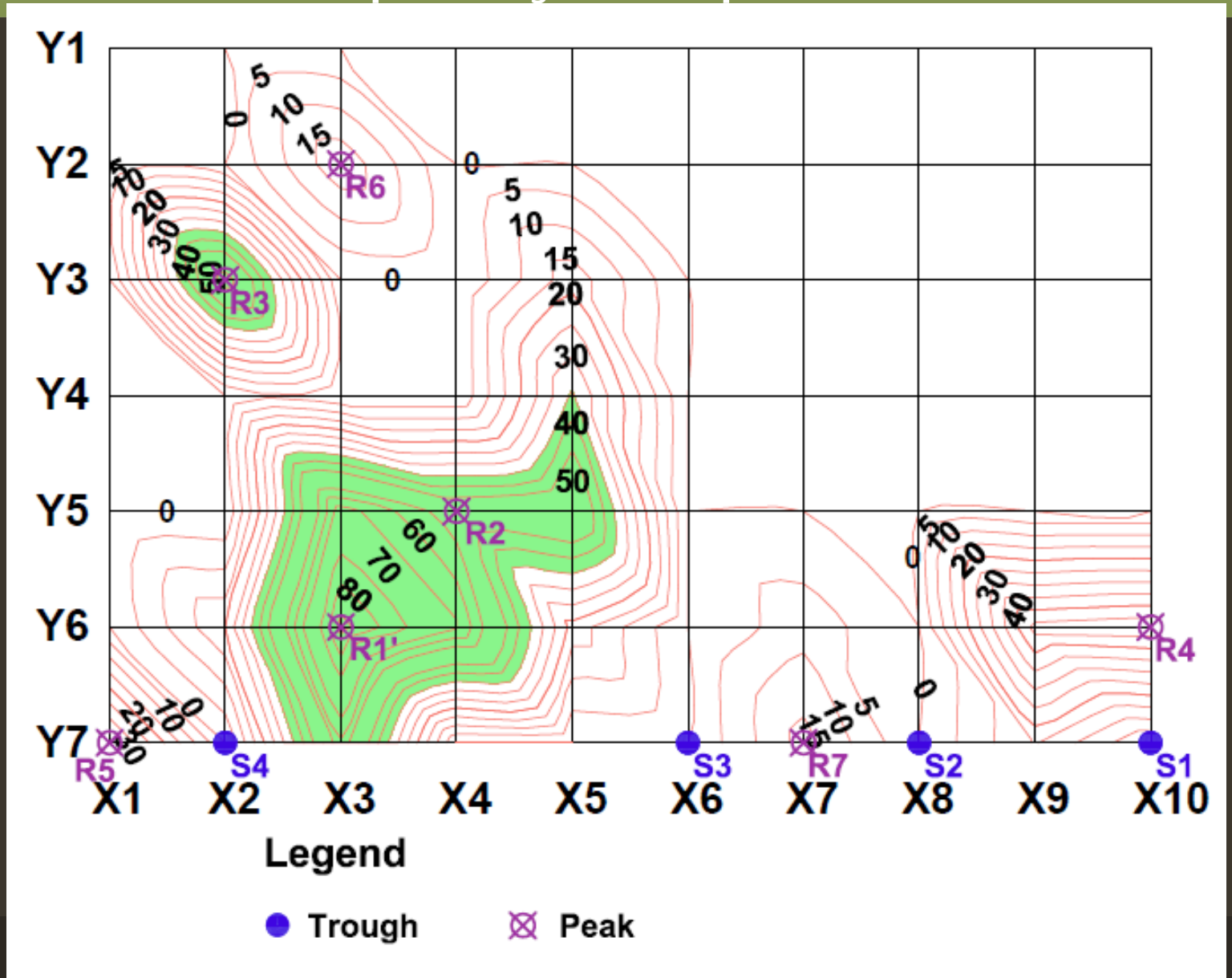
Moisture Contours Map for T_2 = 9:00pm, PT Room,11/6/2015



Moisture pattern stabilized in 1hr.

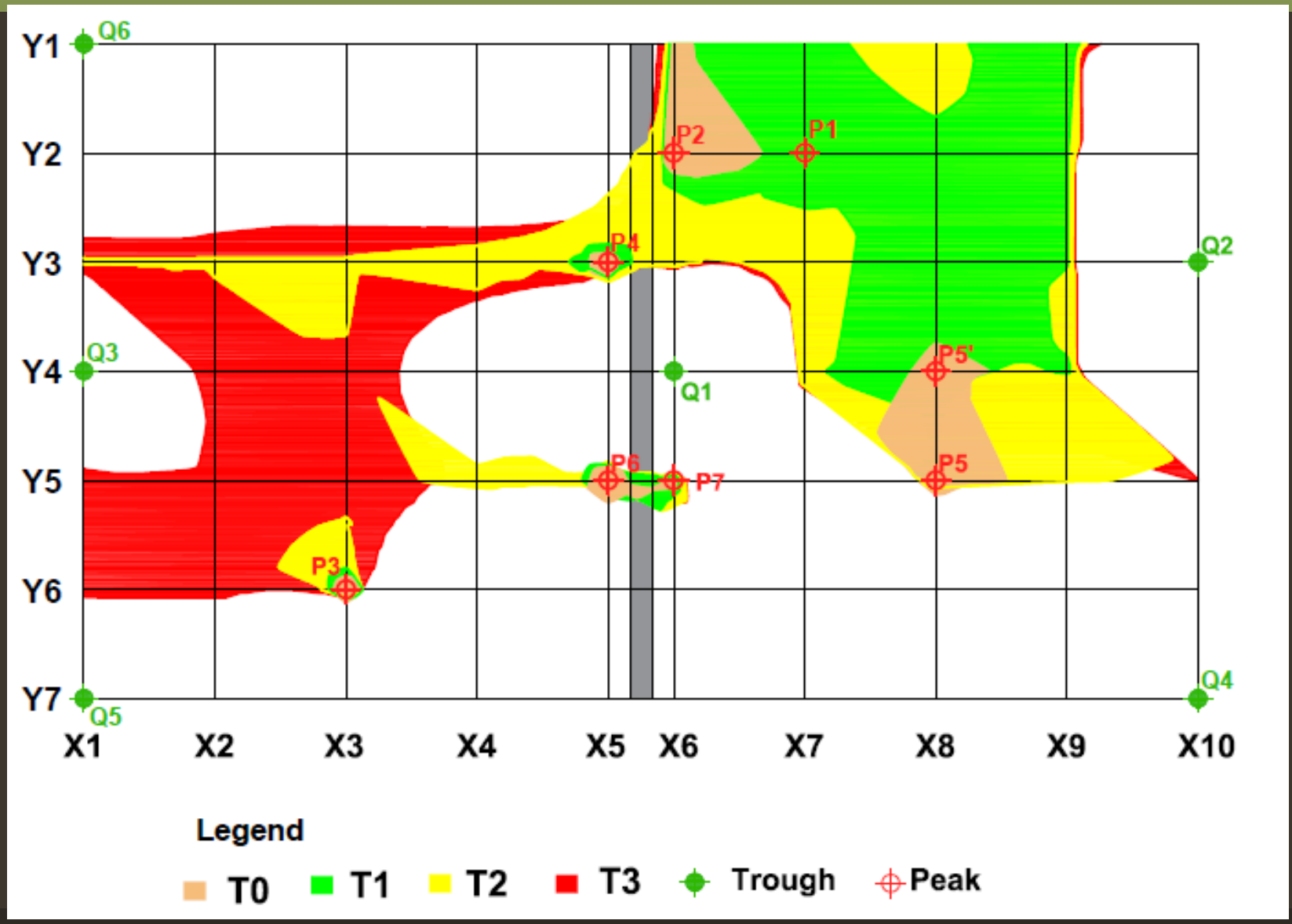
Field Study of Seepage in Tung Chung Case

Moisture Contours Map for T_3 = 9:30pm, PT Room,11/6/2015



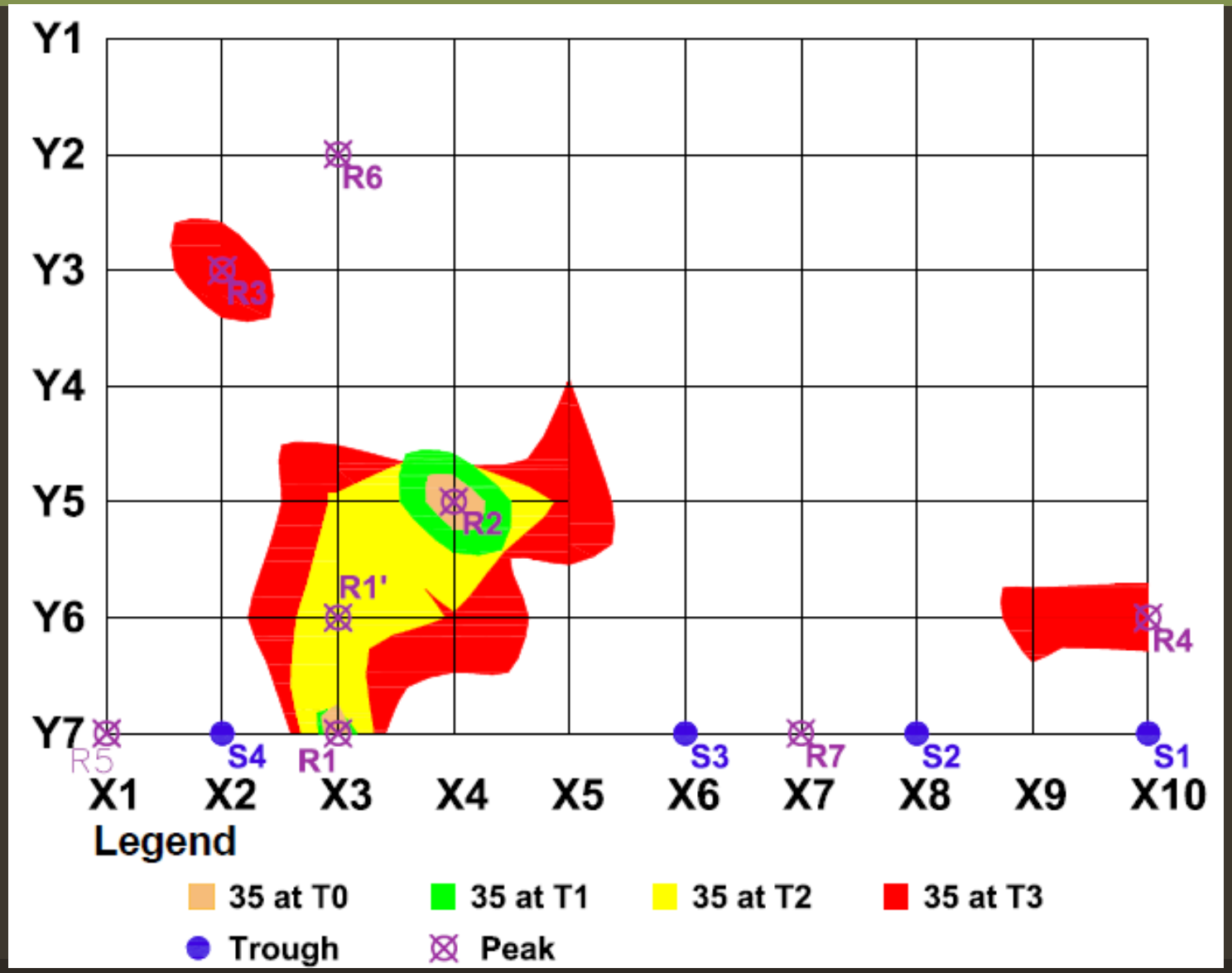
Field Study of Seepage in Tung Chung Case

Peaks, Troughs & Propagation of 95-contours with time from DR scanning



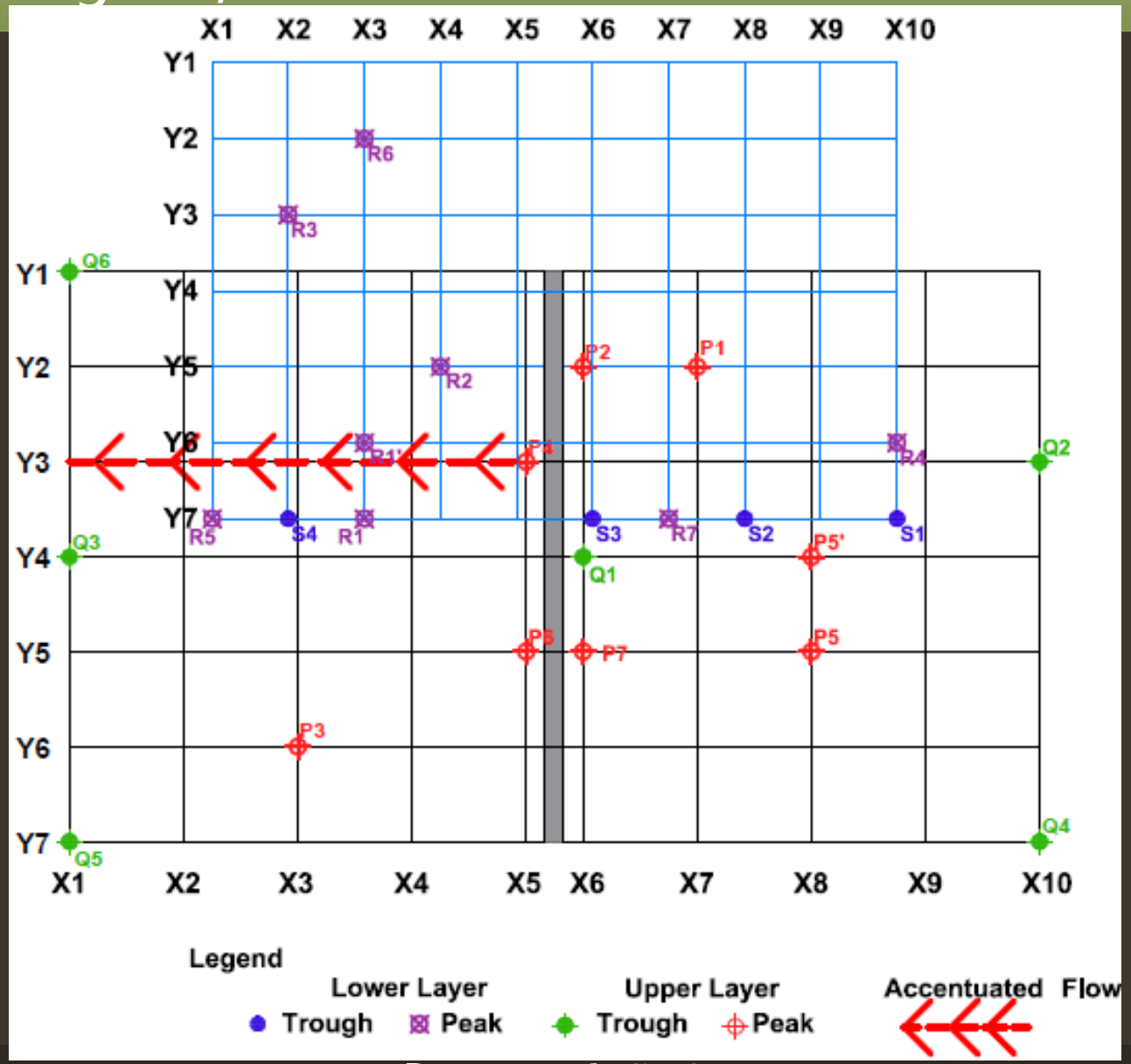
Field Study of Seepage in Tung Chung Case

Peaks, Troughs & Propagation of 35-contours with time from PT Room scanning



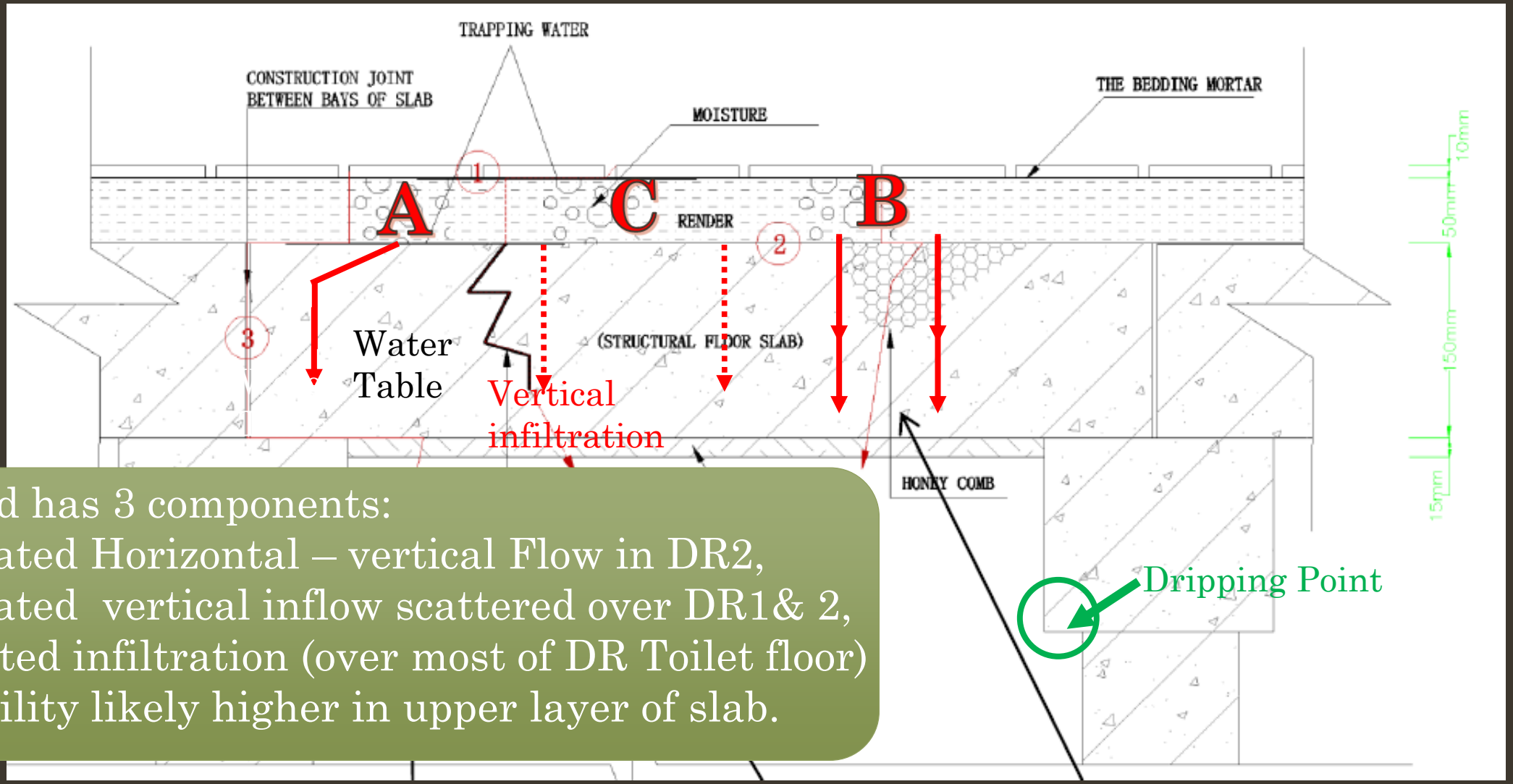
Field Study of Seepage in Tung Chung Case

Potential Ingress, Exit & Accentuated Flow Path in RC Slab



Tung Chung Case Study

Conclusion from Ponding-Scanning Study



- Flow field has 3 components:

A: Accentuated Horizontal – vertical Flow in DR2,

B: Accentuated vertical inflow scattered over DR1& 2,

C: Distributed infiltration (over most of DR Toilet floor)

- Permeability likely higher in upper layer of slab.

Corollary

- Impermeability of surface layer of slab may have been impaired during alteration works for change of use of premises.

- Improving water tightness of tile binding layer may be more economical remedy to a mildly leaky floor slab.

New Method of Seepage Investigation For Enhancement to Current Practice

A. E. coli/salinity test to distinguish foul water

B. General assessment, dripping measurement & Initial Scanning of seepage site

C. Ponding- scanning test on both sides of seepage site

To identify inflow pattern and location

Application to investigating building seepage case in Shan Shui Po

Conclusion of SSP Study from Scanning of ceiling only

1. Seepage inflow from upstairs toilet floor and from UBW on flat roof.
2. Appropriate follow up action:-
   - Repair by concerned owners, or
   - Report to BD/FEHD for enforcement action.

Conclusion & Recommendation from 3 Field Studies

1. Seepage flow may include both distributed flow and accentuated paths.

2. Integrated Ponding – scanning test gives reliable indication of flow field and ingress point of seepage in both wall & floor slab of building.

3. JO may now return the responsibility for general seepage investigation to owners and intervene only in cases of public health or safety.

4. Relationship between renovation practice and building seepage should be investigated.

Methodology of Seepage Investigation

溯洄從之，道阻且長；
溯游從之，宛在水中央。

---詩經 蒹葭篇

Philosophy Applicable to
Building Maintenance and …Governance

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This research project is funded by the Central Policy Unit of the Hong Kong Special Administrative Region Government under **Project No.: 2014.C.006.14C** of Public Policy Research Funding Scheme. Works Bureau seconded an engineer to the HKAES project team. Team members assisted in the study. Several organizations participated in the filed study.

Thank You !