CONMAT'15

Universal Moisture Transport Model in Concrete under Natural Environment

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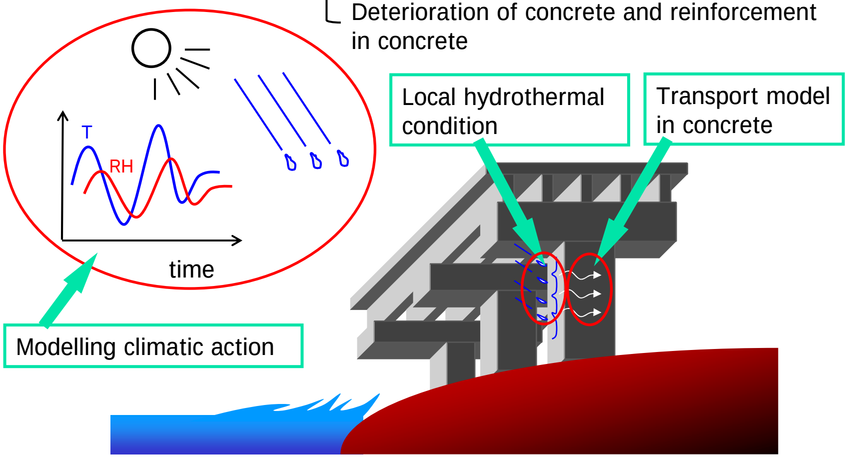
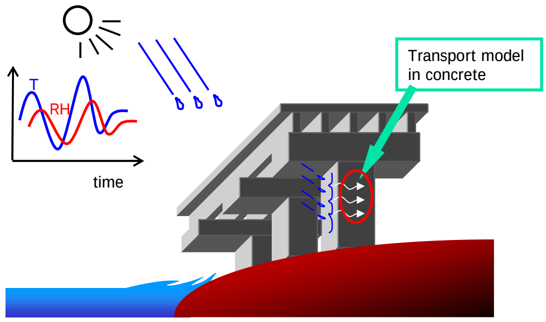
Moisture content in concrete

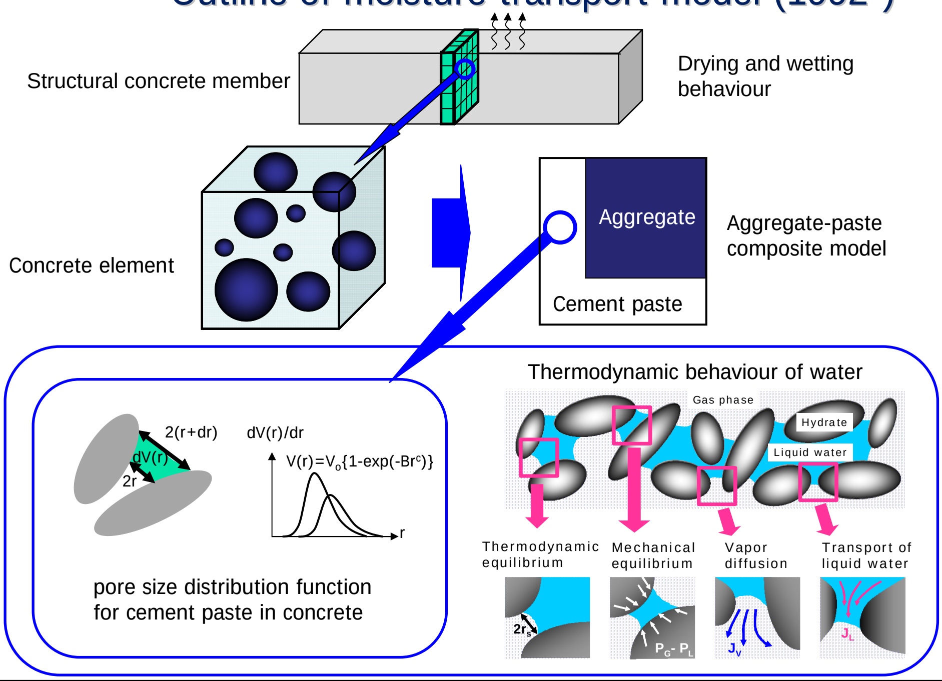
- Shrinkage and creep of concrete
- Transport of aggressive agent in concrete
- Deterioration of concrete and reinforcement in concrete



Moisture transport model in concrete



Outline of moisture transport model (1992-)



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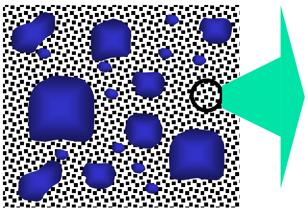
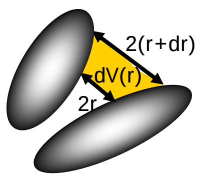
Micropore structure of concrete

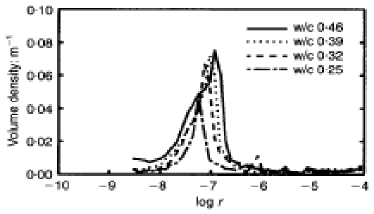


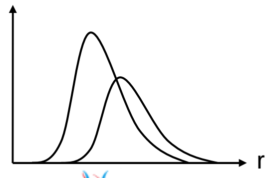


$V(r)=V_o\{1-\exp(-Br^c)\}$

Pore size distribution function

pore size distribution measured by mercury injection method





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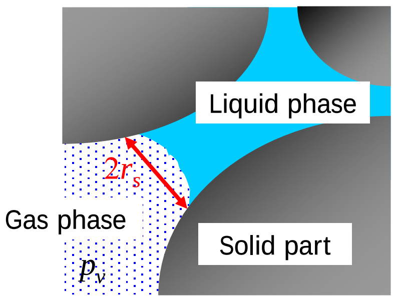
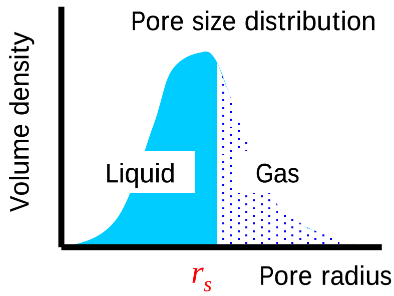
Thermodynamic equilibrium of liquid and gas in pores





Kelvin equation

(capillary condensation theory)

$$\ln \frac{p_v}{p_{vo}} = -\frac{2\gamma M_w}{RT\rho_l}\frac{1}{r_s}$$

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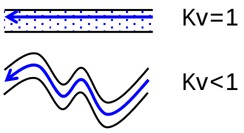
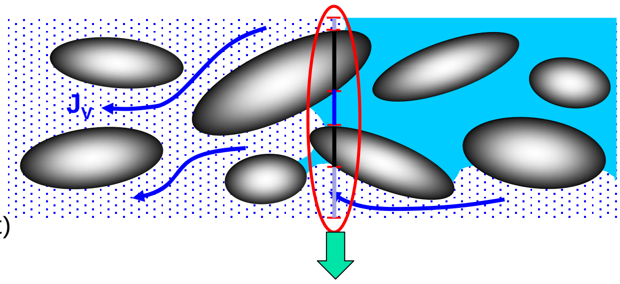
Transport of vapour in pore structure



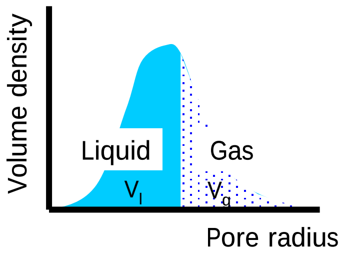
Kv: tortuosity (material constant)



$$J_v = -K_v V_g D_{vo}\, grad\rho_v$$

Diffusion in free space

Vg: Volume fraction of gas phase (variable)



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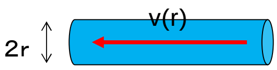
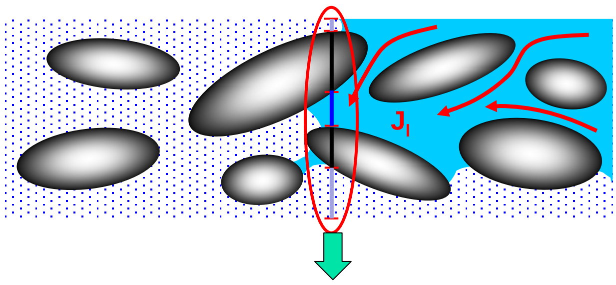
Transport of liquid water in (non-saturated) pore structure

Laminar flow in cylindrical straight pore



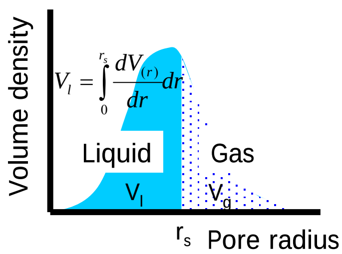
$$v(r) = -\frac{r^2}{8\mu}grad(p_l)$$



$$J_l = \int_0^{r_s}\left[\rho_l \frac{dV_{(r)}}{dr}\left\{-K_l \frac{r^2}{8\mu} grad\left(-\frac{2\gamma}{r_s}\right)\right\}\right]dr$$

K_l: tortuosity (material constant)

Transportation of liquid water takes places in saturated pores.



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Capillary suction from concrete surface

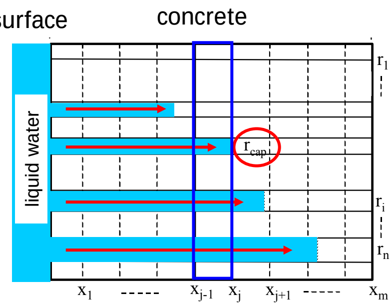
Velocity in each pore

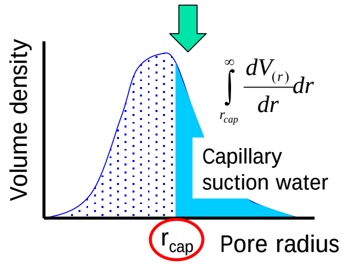
Capillary suction in a horizontal straight vessel

$$\frac{dx_{ri}}{dt} = \sqrt{\frac{r_i \gamma}{8 \mu t}}$$

$$J_l = \int_{r_{cap}}^{\infty} \left(\rho_l \frac{dV(r)}{dr} \sqrt{K_{lp} \frac{r\gamma}{8\mu t_{cap}}} \right) dr$$

K_{lp}: tortuosity (material constant)

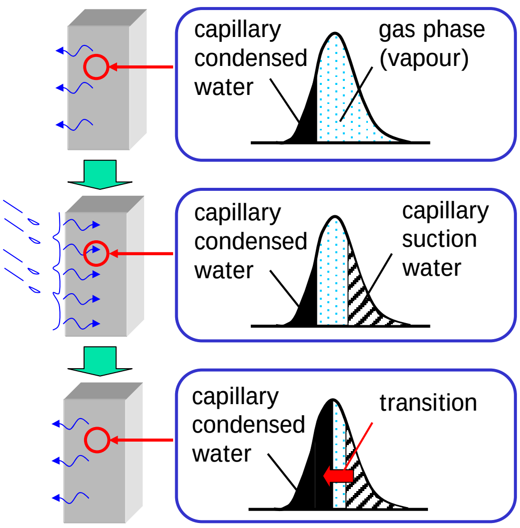




Capillary suction water fills greater pores faster.

Cyclic drying and wetting

drying process



Diffusion of vapour and liquid water in non saturated concrete

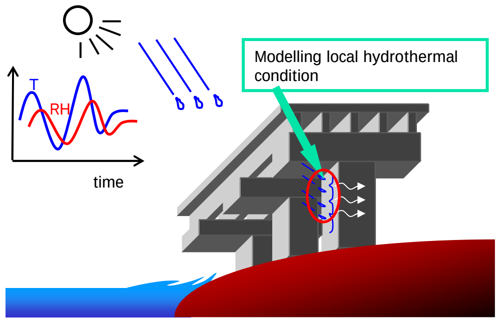
wetting process

Capillary suction from the surface

drying process

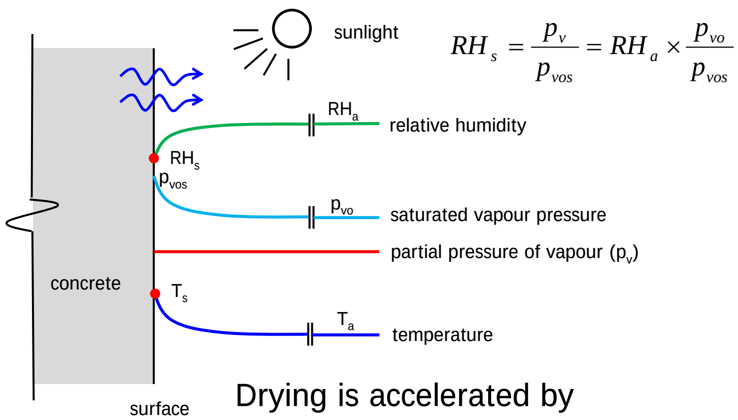
Diffusion of vapour and liquid water in non saturated concrete

Modelling local hydrothermal condition



Local hydrothermal condition

Influence of sunlight

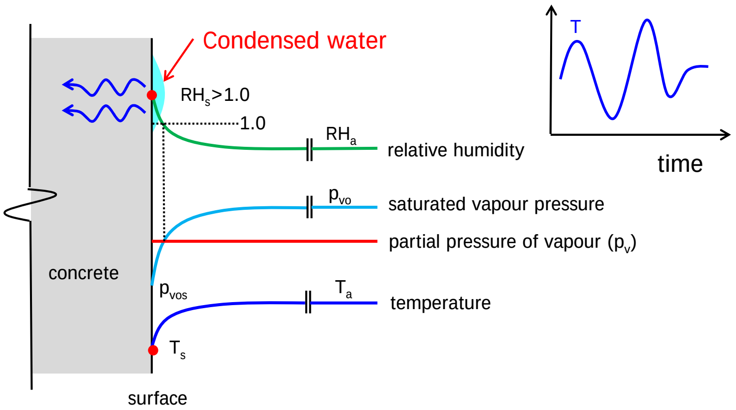


$$RH_s = \frac{p_v}{p_{vos}} = RH_a \times \frac{p_{vo}}{p_{vos}}$$

Drying is accelerated by temperature rise on the surface

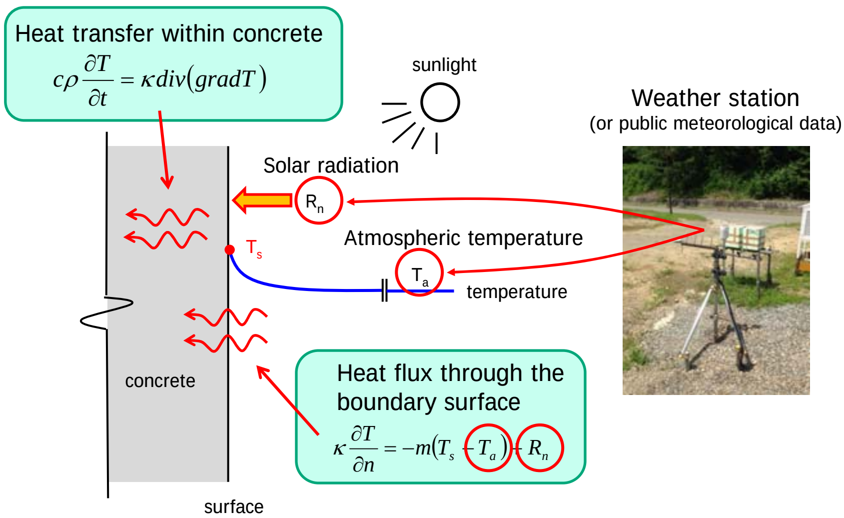
Local hydrothermal condition

Influence of time-dependent change of atmospheric temperature



Wetting with condensed water on the surface

Estimation of surface temperature of concrete by heat transfer analysis



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Verification of moisture transport model and local hydrothermal condition model with field exposure test

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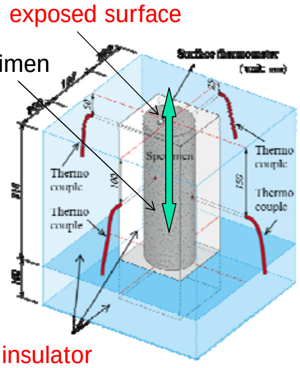
Specimens and exposure test

exposed surface

Specimen



insulator

one-dimensional heat and moisture transfer

Exposure test

Case A: subjected to temperature and humidity change

Case B: subjected to temperature and humidity change, rainfall and sunlight

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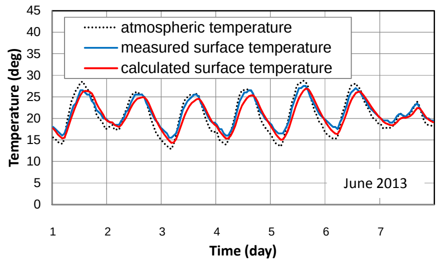
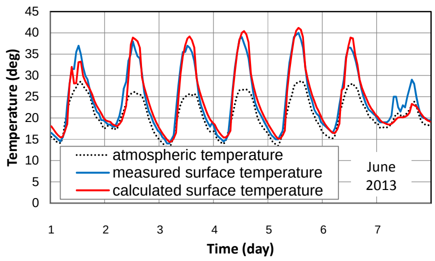
Experimental and analytical surface temperature

Case A

atmospheric
experiment
analysis

Case B

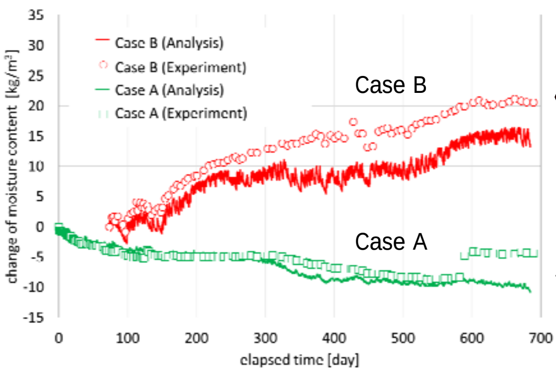




Case A: subjected to temperature and humidity change

Case B: subjected to temperature and humidity change, rainfall and sunlight

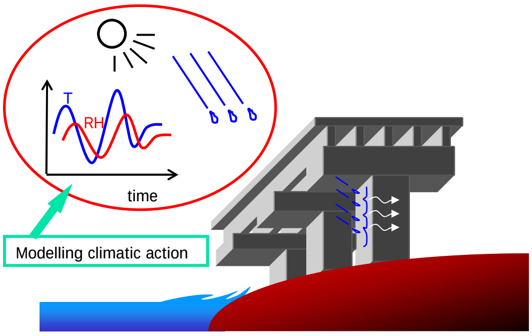
Experimental and analytical drying and wetting behaviour



Case B: subjected to temperature and humidity change, rainfall and sunlight

Case A: subjected to temperature and humidity change

Modelling climatic action



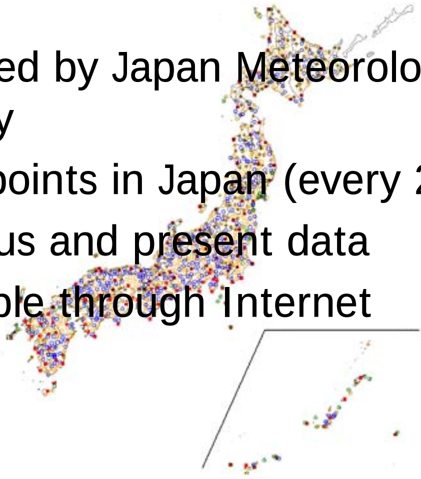
Climatic actions affecting moisture transport in concrete

- Temperature
- Relative humidity
- Rainfall (precipitation, hours of rain)
- Sunlight (solar radiation, hours of sunlight)

How to obtain previous climatic data at the location of the structure?

How to estimate future climatic action to be used in long term simulation?

AMeDAS (Automated Meteorological Data Acquisition System)



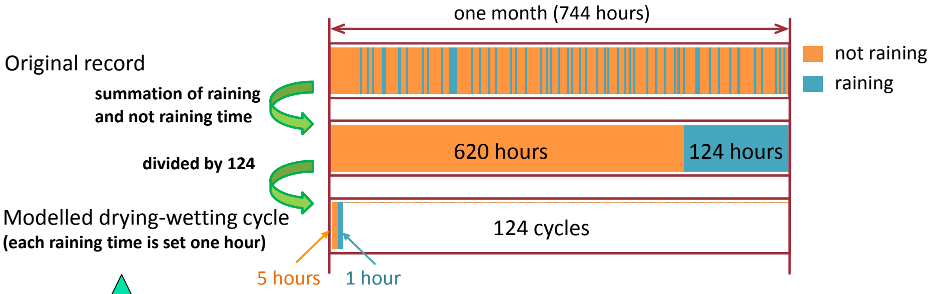
- Provided by Japan Meteorological Agency
- 1300 points in Japan (every 20km)
- Previous and present data
- Available through Internet

Modelling of temperature, relative humidity, and global solar radiation based on AMeDAS data

original temperature data

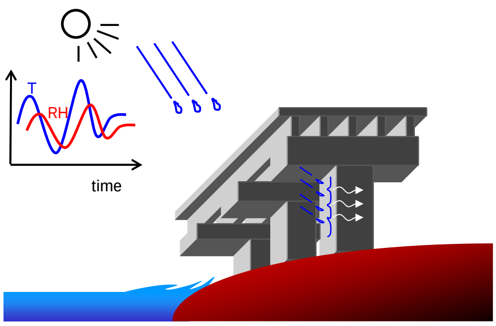
hour	1st January	2nd January	3rd January	...	30th January	31st January	Averaging	Averaged hourly temperature in January
0	7.8	3.7	6.3	...	1.8	4.3		3.78
1	5.2	3.2	6.5	...	1.9	4.1		3.54
2	7.6	3.1	6.2	...	1.3	3.3		3.44
3	7.4	2.2	5.9	...	1.2	3.0		3.54
4	7.2	1.6	5.2	...	1.2	3.2		3.25
.	.	.	.		.	.		.
.	.	.	.		.	.		.
.	.	.	.		.	.		.
23	5.3	6.2	6.6	...	1.4	1.2		4.28

Modelling of wetting action by rain based on AMeDAS data

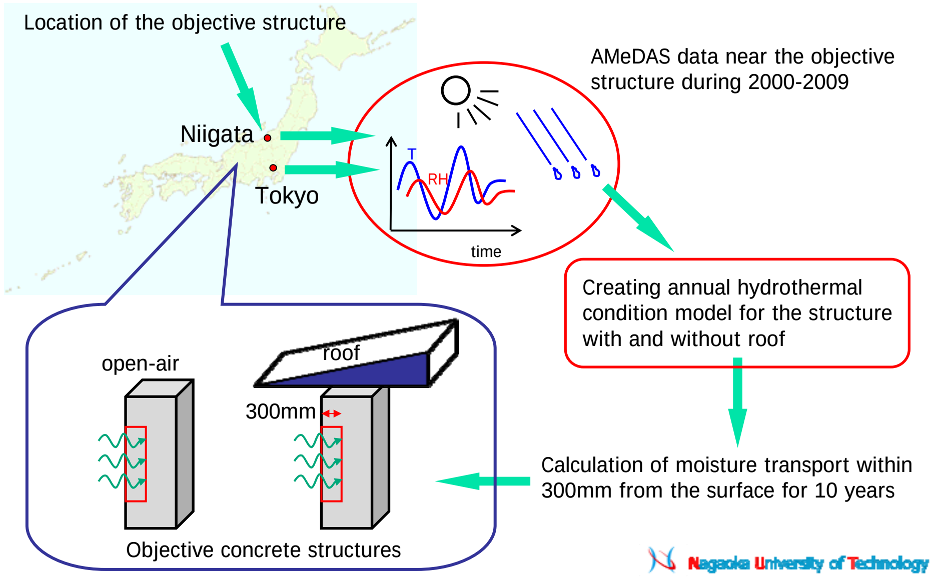


The length of one cycle by which the effect of rain is adequately represented was determined based on sensitivity analysis (2014).

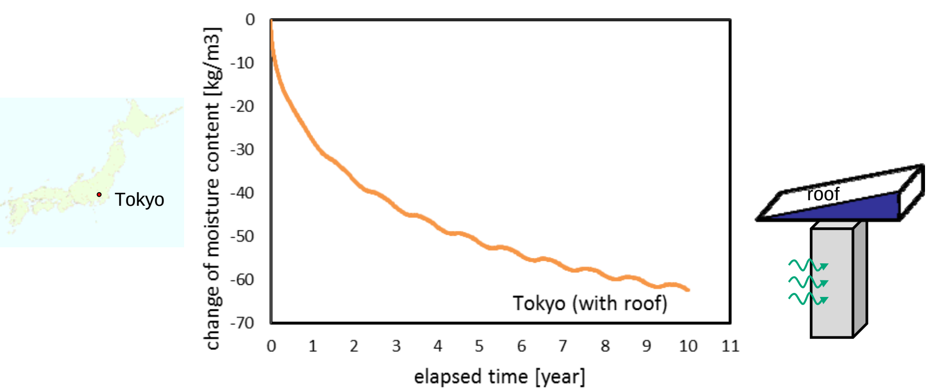
Numerical simulation of long term drying and wetting behaviour of concrete under natural environment



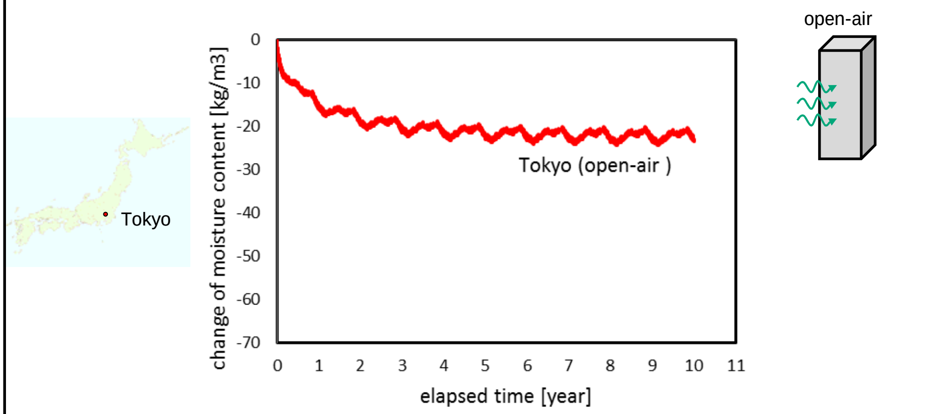
Procedure of numerical simulation of long term drying and wetting behaviour of concrete



Computational results of time-dependent change of average moisture content in concrete



Computational results of time-dependent change of average moisture content in concrete



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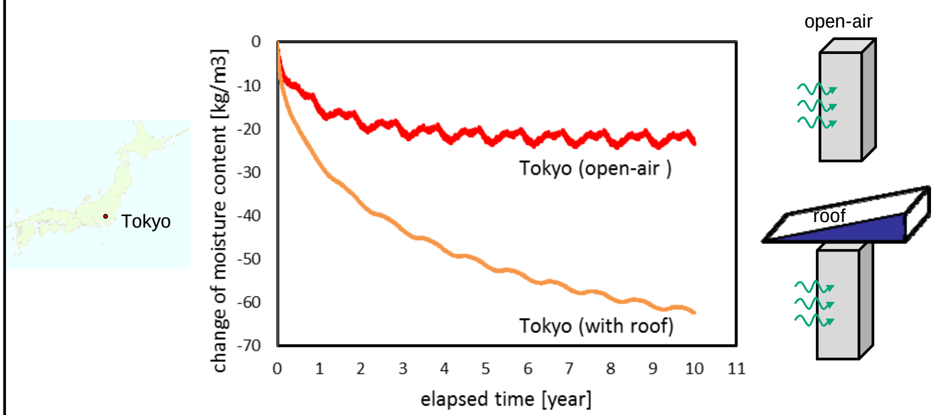
Computational results of time-dependent change of average moisture content in concrete



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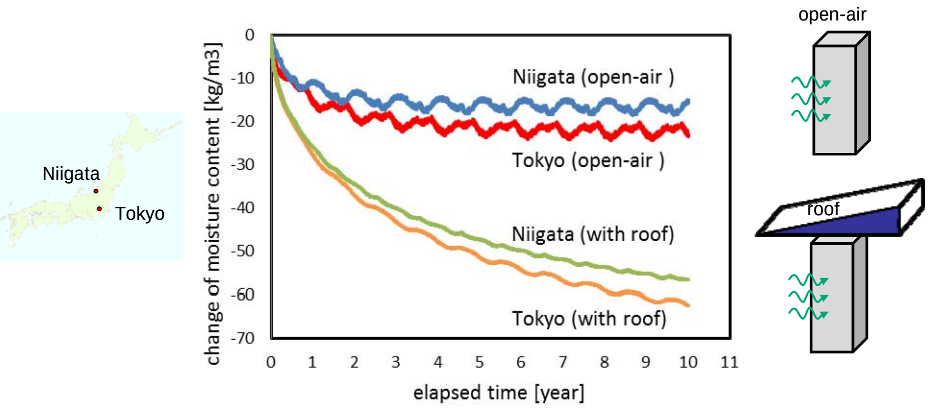
Computational results of time-dependent change of average moisture content in concrete



Conclusion

- The enhanced moisture transport model in concrete considers coupled transport of heat, vapour and liquid water in concrete pore structure, capillary suction from the surface, condensation of vapour on the surface and acceleration of evaporation by direct sunlight.
- Local hydrothermal condition of the objective structure, which directly affect drying and wetting of concrete, is evaluated in terms of temperature, humidity, rain fall, sunlight and their time-dependent changes.
- Climatic action on the structure at the service location is taken into account based on AMeDAS (Automated Meteorological Data Acquisition System), which is provided by JMA (Japan Meteorological Agency) through Internet.

THANK YOU