# Review on the Strength Development Required for the Concrete Structure of Nuclear Power Plant under Cold Weather Conditions

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## 1. Introduction

As a part of a Department of Energy-Nuclear According to the specifications for the construction execution for a nuclear power plant (NPP), the cold weather concrete should be facilitated that comply with the regulations of ACI-306R[1]. Here, in terms of the standards applied to the cold weather concrete, such concrete should be applied in the case where the daily average temperature is 5℃ or less. So, according to the analysis on the average temperature in winter over the last one year at each NPP construction area, it was found that such had lowered by about 0.5 - 2℃ as compared to the temperature during the normal years (the last ten years)[3] and the number of days applied to the cold weather concrete according to the ACI regulations was shown as 83, so as around 1/4 of year falls into the cold weather conditions and furthermore the recent weather is getting severe, it is necessary to perform the appropriate insulation curing for the cold weather concrete.

On the other hand, according to the regulations with regards to the curing conditions for cold weather concrete, the insulation curing of such should be appropriately performed under an environment of 5℃ or greater until the strength of 3.5 MPa (500 Psi) develops. Likewise, according to the regulations regarding the cold weather concrete in the domestic concrete specifications [2], the insulation curing should be performed until a strength development of 5 MPa (715 Psi) considering the safety factor indicated to the ACI regulation under the temperature of 5℃ or greater.

According to the above-mentioned regulations, the NPP structure is required to develop a minimum strength of 5 MPa or greater, and to maintain such important qualities, including strength development, early anti-freezing and duality under cold weather conditions. However, even though the early strength of 5 MPa or greater is secured under the recent abnormal weather conditions and cold weather conditions, if the structure is exposed to continuous cold weather conditions after the protection equipment, including the curing coat are removed, the structure's durability may lessen as compared to the concrete cured under the standard curing temperature conditions in the spring and fall, however, the studies on this status still remain poor.

Accordingly, this study attempted to verify the adequacy of the insulation curing management standard, which is currently presented, during the construction period of the cold weather concrete, through reviewing the freeze-thaw resistance after curing until the point of 5 MPa, then exposing such to a certain cycle of freeze-thaw environment under the continuous cold weather conditions and then finally performing the standard curing for 28 days.

## 2. Experiment plan and method

### *2.1 Design of experimental*

This study obtained the test plan as Level 2 of cold weather curing and standard curing along with 30 cycles of freeze-thaw after curing until 5 MPa (715 Psi) under 5℃ as an early curing method against the Level 1 of NPP concrete showing the design standard strength of 28 MPa (4000 Psi). As for the test items, the slump and air contents were measured in fresh concrete and the compressive strength and freeze-thaw resistance in hardened concrete.

As for the mixture items, the fly ash (FA) being currently used at NPP construction sites applied a mixture replaced by 20%. Also, according to the NPP construction specifications, it took the mix design adjusting the water reduction agent and the AE agent in order to meet the target slump (120±25 mm) and air contents (4.5±1.5%).

Table Ⅰ: Mixture proportion

| Str (Psi) | S/a (%) | Gmax (") | WRA (%) | Unit weight ($kg/m^3$) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | W | C | FA | Agg | Sand | WRA | AEA |
| 4000 | 46.7 | 3/4 | 0.64 | 162 | 260 | 64.8 | 938 | 822 | 2.08 | 0.20 |

### *2.2 Test method*

In the test method of this study, the concrete was mixed by using the 1-axis forced pan-type mixer. In terms of the test of fresh concrete properties, the slump was measured by KF F 2402 and the air contents by KS F 2421. As for the test of hardened concrete properties, the cylindrical specimens were manufactured as by KS F 2403 and the compressive strength was measured by KS F 2405. The freeze-thaw resistance was performed by the air-freeze and water-thaw method of KS F 2456 through the manufacturing of square specimens of 100x100x400mm. As for the temperature range of freeze-thaw test, through setting the central temperature of the specimen as -18.0℃~+4℃, setting the time of one cycle as 4 hours and measuring the 1st resonate frequency and the mass of the specimen up to 300 cycles at an interval of each 30, the relative dynamic modulus of elasticity could be obtained.

This study then planned a test method to reproduce the construction conditions of an NPP structure under a cold weather environment. First, considering the protective curing for the prevention of early freezing, the sealed curing was performed under the temperature of 5℃ until the development of 5 MPa after placing the concrete. Thereafter, after exposing the concrete to the freeze-thaw environment of 30 cycles in order to consider the continuous exposure to the cold weather environment after removing the protective equipment, the freeze-thaw resistance was measured after the required curing period as shown in Figure 1.

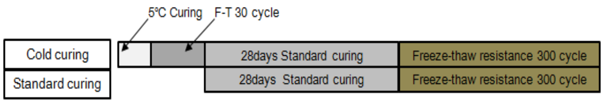


Fig.1 Flow of Curing and tests

## 3. Result and discussion

### *3.1 Properties of compressive strength*

Figure 2 shows the strength change dependent on the age process of the concrete by curing conditions.

First, as this study measured the compressive strength to the planned age in the case of standard curing conditions and conducted the test through a method to expose to the 30 cycles of freeze-thaw after curing at the temperature of 5℃ until reaching 5 MPa in the case of cold weather curing, the strength value of the standard curing and the cold weather curing thus could not be measured at the same age.

In the case of cold weather curing, however, the compressive strength was shown as 27 MPa in the actual age of 36 days, namely at the age of 28 days after the early freeze-thaw cycle was complete while as 30 MPa at the age of 28 days in the conditions of standard curing; the strength had decreased by about 9% in cold weather curing compared to standard curing. It was found that the results were caused by an insufficient hydration reaction resulting from low temperatures as the concrete was exposed to a cold weather environment in the early curing.

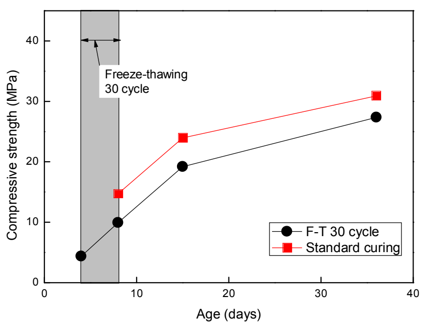


Fig 2. Compressive strength according to curing method

### *3.2 Properties of resistance to freezing and thawing*

Figure 3 shows the relative dynamic modulus of elasticity according to the freeze-thaw cycle of the concrete by curing conditions.

First, in the case of standard curing, the relative dynamic modulus of elasticity smoothly lowered as compared to the early time and showed as about 80% at 300 cycles - comparatively better. In the case of cold weather curing, however, it lowered to 76% at 30 cycles and as the freeze-thaw cycle proceeded, it gradually dropped to 57.7% at 210 cycles – less than the KS regulation value of 60%.

As a result, even though the strength of 5 MPa or more was secured in the cold weather environment, when it was continuously exposed to cold weather conditions, it is thought that the durability, such as the freeze-thaw resistance would lower significantly. Accordingly, in the cold weather concrete construction execution of the high durability-required structure such as an NPP structure, it was deemed necessary to take actions to apply the concrete curing period and curing engineering whilst considering the safety factor

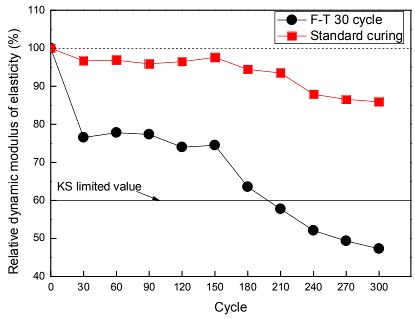


Fig 3. Relative dynamic modulus of elasticity with cycles

## 4. Conclusion

This study reviewed the freeze-thaw resistance of concrete exposed to continuous cold weather environmental conditions after early curing. As a result, it was found that even though such had cured up to 5 MPa at an early time, the NPP concrete exposed to the continuous cold weather environment after the curing coat was applied, and so on were removed showed a more drastic decrease in the freeze-thaw resistance as compared to the standard curing concrete. Accordingly, it could be known that the 5 MPa, the insulation curing standard of cold weather concrete, was set lower in terms of durability.

## ACKNOWLEGMENT

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