CONCRETE SPECIFICATIONS OF FREEWAY STRUCTURES IN TAIWAN

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SUMMARY

The north-south 1\textsuperscript{st} freeway located in west corridor of Taiwan completed in 1978. In 1987, the 2\textsuperscript{nd} freeway started its construction and was opened to traffic in 2004. More than 30 years of freeway construction experiences, the specification of freeway structures has been amended and revised several times. Concrete is the most important and widely used material in freeway structures so that its specifications had a remarkable modification. In this paper, the scheme of freeway network in Taiwan will be introduced first, then concrete specifications of freeway structures and characteristics of the specifications will be discussed. In order to meet the requirements of the new generation freeway structures, concrete specifications have brought in the certification system for ready mix plant, qualification of engineers and technicians, payment factor of concrete, self-compacting concrete, and slag cement, etc. to ensure the quality of concrete structures.

INTRODUCTION

Taiwan, a mountainous island with total area 36,000\textsuperscript{2}, was once called “Formosa”, which means “beautiful island”. It is 394 kilometers long and 144 kilometers broad at its widest point. The most prominent topographic feature is 270-kilometer central mountain range where more than 200 peaks towering over 3,000 meters above sea level obstruct the transportation of the east and the west of the island. Most of the population lived in the west corridor of Taiwan.

Since the opening of the 1\textsuperscript{st} Freeway in 1978, Taiwan has experienced a remarkable economic progress. However, the soaring numbers of cars as well as the urgent demand for transportation have caused severe traffic congestion along the 1\textsuperscript{st} Freeway. Thus, the Northern Second Freeway Project and the Extension of the Second Freeway Project were planned and constructed since 1987.

The Northern Second Freeway was opened to traffic in 1996. With a length of 99 km, the

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main route stretches from northern edge of Taipei metropolitan to Hsinchu. In addition, it includes a 6-km-long Taipei connection route and a 12-km-long inner beltway linking to CKS International Airport. The Extension of the Second Freeway started its construction in 1993. Extending the Northern Second Freeway to Keelung in the north and to Pingtung in the south, it includes a main route with a length of 333 km and 4 branches with a total length of 68 km. The extension of second freeway has been completed and opened to public in 2004.

Geographical barriers and other natural factors have led slow development of eastern Taiwan coastal region. For this reason, the cross-island expressways and eastern expressway are constructed to promote the accessibility of eastern coastal region and support the national policy of an eastward shift of industry. The Taipei-Suao Expressway started its construction in 1992. It is the first east-west expressway crossing the central mountain range barrier. Besides, the Eastern Expressway with a length of 240km stretches the network from Suao via Hualien to Pingtung is under planning too. The Southern Cross-Island Expressway running from Pingtung to Taitung was planned. Also, west section of the Central Cross-Island Expressway with a length of 37 km is under construction. These will connect the Second Freeway in the west and the Eastern Expressway in the east, and then turn out to be a round-island expressway network (Figure 1).

To overcome geographical barriers and effectively utilize of land, freeways in Taiwan has three major types of structures; bridge, tunnel and embankment, more than 70% of the structures are bridges and tunnels. Considering the sources and quantities of engineering material available, produced technology, material properties, economical reasons and sustainable development, concrete structures become the main choice for freeway, especially in bridges.

Concrete has been used for more than hundred years. It has several advantages such as durable, easy to produce and cheap. However, problems of concrete such as honeycomb, cold joint, cracks and insufficient strength that affect the integrity of the structure is still being found in many places. The quality control of concrete still depends on very intensive work, such as the quality control process of material; equipment precision and ability of ready mix plant; transportation and construction techniques (placing, curing and protection). Therefore, concrete specifications assigned in the construction contract become very essential for the success of structures.

**CONTENTS OF SPECIFICATIONS**

1st version of concrete specifications for freeways in Taiwan issued in 1973; It has been regulated for 1st freeway construction. Then, it was revised in 1974, 1987, 1991, 1996 and 2002. The version of 2002 has made a huge modification to coordinate with the continuity of concrete specifications issued by Public Construction Commission. To meet requirements of special use, special specifications was added in some contracts.

The major sections of concrete specification 2002 includes: (1). General rule, (2). Product, (3). Construction, and (4). Measured and payment. Details of each section are as follows:
1. General rule
   1.1 Summary
   1.2 Scope of works
      1.2.1 Transport, storage and treatment
      1.2.2 Standard of cement, aggregate, water, chemical admixture, chemical curing agent, waterproofing paper and polyethylene film
      1.2.3 Mix design and required compressive strength
      1.2.4 Mixing and curing
      1.2.5 Compressive strength test and measured of water solvable chloride content
   1.3 Related sections
      1.3.1 Chapter02054 - Material production at quarry factory
      1.3.2 Chapter02751 - Cement concrete pavement
      1.3.3 Chapter03052 - Portland cement
   1.4 Related criterions
   1.5 Definition
      1.5.1 Concrete grade
      1.5.2 Compressive strength
      1.5.3 Second-rate quality concrete
   1.6 Transport, storage and treatment
      1.6.1 Transport
      1.6.2 Storage
      1.6.3 Protection

2. Product
   2.1 Material
      2.1.1 Aggregate
      2.1.2 Cement
      2.1.3 Water
      2.1.4 Chemical admixture
      2.1.5 Chemical curing agent
      2.1.6 Waterproofing paper and polyethylene film
      2.1.7 Water solvable chloride content
   2.2 Design and manufacture
      2.2.1 Concrete mix design
      2.2.2 Trial mix

3. Construction
   3.1 Construction method
      3.1.1 Mixing
      3.1.2 Mix plant mixing and truck mixing
      3.1.3 Hand mixing
3.1.4 Chemical admixture
3.1.5 Curing
3.2 Inspection
3.2.1 Material quality
3.2.2 Compressive strength test

4. Measured and payment
4.1 Measured
4.2 Payment

Major characteristics of the specification include:
(1) Slag cement and slag powder can be used to replace partial cement
(2) Defined concrete grades by compression strength (f\(^{c}\))
(3) Defined what is “qualify concrete”
(4) Allowable quantity of cementitious material can be used
(5) Set up the relationship between f\(^{c}\) and maximum w/b
(6) No slump range regulations
(7) Steam curing method can be applied
(8) Payment factor of normal concrete
(9) Qualification of engineers and technicians
(10) Ready mix plant certificate
(11) Self-compacting concrete (SCC) applied in bridge piers

Application of Slag Cement and Slag Powder

Slag cement and slag powder have been used in Taiwan for more than 20 years, guidelines of slag cement concrete were published in 2001. China National Standard (CNS) has published related standards such as [CNS3654 Portland slag cement], [CNS12549 concrete and cement mortar use water quench high slag powder]. The type of slag powder used in freeway is grade 120 (finesse \(\geq 5000\text{cm}^2/\text{g}\)). Concrete use slag cement and slag powder as a cementitious material, the replacement of slag powder to cement by weight should not over 30%, if use slag cement, the cement contents 120 grade slag powder should less than 30%

Defined Concrete Grades by Strength

(1) 80kgf/cm\(^2\): apply for backfill or foundation layer;
(2) 175kgf/cm\(^2\): apply for larger section of reinforced concrete structures, drainage facility or plain concrete structures.
(3) 245 and 280kgf/cm\(^2\): apply for pavement, slab, beam, arch, retaining wall, foundation, precast reinforced concrete pile, underwater concrete;
(4) 350 and 420kgf/cm\(^2\): apply for pier, cast-in-place or precast prestressed concrete beam;
(5) 45kgf/cm\(^2\) (flexural strength): apply for cement concrete pavement.

Qualify Concrete

Normal concrete complied the same time with two requirements as listed below can be defined as “qualify concrete”;
(1) The batch of concrete, very three continuity sets of concrete cylinders strength average not
(2) Any set of concrete cylinders strength test results not less than $f'c \leq 350\text{kgf/cm}^2$, $f'c - 0.1f'c$ ($f'c \geq 350\text{kgf/cm}^2$)

Cementitious Material Content in Concrete

Cementitious material content for each strength grade of concrete was suggested in Table 1. This content is to ensure the concrete can reach designed strength, but not a restricted value in contract.

Relationship of $f'c$ and Maximum w/b

Considering factors that might affect the quality of concrete, such as the ability of contractors, material quality variation and production procedure of concrete, each grade of concrete has suggested an allowable maximum w/b (water/binder) ratio (Table 2) to keep its strength at an expected level.

No Slump Range Regulations

Concrete slump test is a very easy way to measure workability of concrete. However, the selection of slump should be responsibility of contractors. Contractors can decided the slump according to the type of structural member, quantity of reinforcement and concrete placing equipment. Specification is not suitable to assign the slump value for each structure.

Steam Curing Method

In 1991 version of specifications, concrete curing method including wet method, chemical curing compound method, waterproof membrane method. In order to comply with the automated construction method of bridge superstructure (such as precast segment method and cantilever method), steam curing was included in 1996 and 2002 versions of specifications.

Payment Factor of Normal Concrete

(1) 1996 Version

Normal concrete, each batch and its sets of test cylinders 28 days average compressive strength as $M$, if $M$ small than $0.85f'c$, concrete should be demolished and recast again without any compensation. When $f'c > M \geq 0.85f'c$, after the analysis by engineers, if result shows that the safety of structure is not influenced and can be accepted, the batch of concrete is being defined as second-rate quality concrete, when $M$ is between $f'c$ and $0.85f'c$, the payment is given as follows:

<table>
<thead>
<tr>
<th>M Value</th>
<th>Payment Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M \geq f'c$</td>
<td>1.0</td>
</tr>
<tr>
<td>$f'c &gt; M \geq 0.95f'c$</td>
<td>0.9</td>
</tr>
<tr>
<td>$0.95f'c &gt; M \geq 0.90f'c$</td>
<td>0.7</td>
</tr>
<tr>
<td>$0.90f'c &gt; M \geq 0.85f'c$</td>
<td>0.4</td>
</tr>
</tbody>
</table>

If a batch of prestressed concrete, each set of compressive strength should greater than $f'c$ and only allow one cylinder compressive strength smaller than $f'c$ but not less than $0.95f'c$, that batch of concrete still can pay by the price listed in contracts, if not, it should be rejected.
(2) 2002 version
Normal concrete not comply at the same time with two regulations as listed below, but being analysed by engineers that the safety of structure is not affected and can be accepted, the batch of concrete is being categorized as second-rate quality concrete.

(1) The batch of concrete, very three continuity sets of concrete cylinders strength average not less than $f'c$;
(2) Any set of concrete strength test results not less than $f'c-35$ kgf/cm$^2$.

If $f'c \leq 350$ kgf/cm$^2$, then $f'c-0.1f'c$ for $f'c \geq 350$ kgf/cm$^2$.

If every batch of concrete, its average compressive strength (M) less than 0.85$f'c$ or analysis results shows that the safety of structure is affected and rejected, concrete should demolished and recast again or strengthen as approval by engineers without any compensation. If $f'c > M \geq 0.85f'c$, the payment factors are given as below:

<table>
<thead>
<tr>
<th>M Value</th>
<th>Compliance Conditions</th>
<th>Payment Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M \geq f'c$</td>
<td>comply with (1),(2)</td>
<td>1.0</td>
</tr>
<tr>
<td>$M \geq f'c$</td>
<td>not comply with (1),(2) the same time</td>
<td>0.95</td>
</tr>
<tr>
<td>$f'c &gt; M \geq 0.95f'c$</td>
<td>not comply with (1),(2) the same time</td>
<td>0.9</td>
</tr>
<tr>
<td>$0.95f'c &gt; M \geq 0.90f'c$</td>
<td>not comply with (1),(2) the same time</td>
<td>0.7</td>
</tr>
<tr>
<td>$0.90f'c &gt; M \geq 0.85f'c$</td>
<td>not comply with (1),(2) the same time</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Qualification of Engineers and Technicians

Ready mix plant should has engineers and technicians as listed below:

(1) One full time quality control engineer, who graduated from college related to civil engineering, and had 3 years experiences in concrete area, also has been attended at least 24 hours courses concerning cement concrete quality control (Table 3).

(2) 2 production technicians, one of them should be high school graduated, had 3 years experiences related to civil engineering (at least 1 year in operating of production of concrete), also has attended at least 24 hours courses in concrete production (Table 4).

(3) 2 full time test technicians, graduated from high school related to civil or material engineering, had 3 years experiences in related work, and has attended at least 24 hours courses in concrete test program (Table 5).

Ready Mix Plant Certificate

To ensure the quality control ability, the ready mix plant who supply concrete for the freeway should summit one of the certificated documents as shown below:

(1) Ready mix plant has a certification related to concrete production and quality control ability issued by government agency, independent agency or academic organization.

(2) Documents indicated the ready mix plant complied with the specifications of Production and quality control standard of ready mix plant, contents of document should include the following items:
   a. Hardware equipment: material storage equipment, material distribution and weighting equipment, mixing equipment, transportation equipment, laboratory equipment;
   b. Raw material control: cementitious material, aggregate, chemical admixture, mixing
c. Quality management system: organization and management; contract review; mix design and control; procurement; maintenance of produce equipment; control of produce process; raw material inspection, inspection during processing, produce final inspection, inspection and test record; ability of inspection and test; control of inspection and measure equipment; client complain, non-quality product control and rectify measures; transport, storage, protection and deliver goods; training; statistics analysis; inside audit.

SCC in Bridge Piers

Based on earthquake design, quantity of reinforcement in bridge piers and columns has increased that induced the difficulty of concrete placing. Self-compacting concrete (SCC) has excellent flowing ability and passing ability between rebar that being used in the bridge of 2nd Freeway. Now, nearly 200,000m³ SCC with the f’c=350Kg/cm² and f’c=420Kg/cm² was being applied in NanTou Freeway and constructed from January 2005.

CONCLUSIONS

Concrete is a very important material and has long history application in structures, but its quality of production involved sources of material, production technology, equipments and personal ability, etc. Moreover, structural design also influenced the quality of concrete. Freeway structures are very important to the economic development of a country and society activity. The quality of concrete shall be essential to structures. In order to ensure the quality of concrete, the specifications of concrete should be based on functional purposes, enlarged the availability of materials, simplified the construction procedure and quality control work, enhanced the continuity of production and construction, and engineer education.
Table 1 Reference content of cementitious material in concrete (Unit: Kg/m³)

<table>
<thead>
<tr>
<th>Grade, f’c (kg/cm²)</th>
<th>80</th>
<th>175</th>
<th>245</th>
<th>280</th>
<th>280(Water)</th>
<th>350</th>
<th>420</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference total weight</td>
<td>200</td>
<td>275</td>
<td>350</td>
<td>400</td>
<td>425</td>
<td>475</td>
<td>500</td>
</tr>
<tr>
<td>Minimum content of cementitious (only use cement)</td>
<td>180</td>
<td>248</td>
<td>315</td>
<td>360</td>
<td>383</td>
<td>428</td>
<td>450</td>
</tr>
<tr>
<td>Minimum content of cementitious (use cementitious other than cement)</td>
<td>190</td>
<td>262</td>
<td>333</td>
<td>380</td>
<td>404</td>
<td>452</td>
<td>475</td>
</tr>
</tbody>
</table>

Table 2 Relationship of f’c and maximum w/b

<table>
<thead>
<tr>
<th>f’c (kg/cm²)</th>
<th>80</th>
<th>175</th>
<th>245</th>
<th>280</th>
<th>280(water)</th>
<th>350</th>
<th>420</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. w/b</td>
<td>0.90</td>
<td>0.67</td>
<td>0.51</td>
<td>0.45</td>
<td>0.50</td>
<td>0.40</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Table 3 Training courses for quality control engineers (42hrs)

<table>
<thead>
<tr>
<th>Time</th>
<th>09:00-12:00(3hrs)</th>
<th>13:00-1600(3hrs)</th>
</tr>
</thead>
</table>
| Day 1| Properties of fresh concrete | 1. Concrete component material
|      |                    | 2. Properties of harden concrete |
| Day 2| Mix design method and examples | Mix design modification and practice |
| Day 3| 1. Concrete produce and construction
|      | 2. Contract and procurement | Concrete quality system |
| Day 4| Statistics quality control practice (I) | Statistics quality control practice (II) |
| Day 5| Statistics quality control practice (III) | Visit ready mix plant and discussion |
| Day 6| Concrete problems analysis and treatment (I) | Concrete problems analysis and treatment (II) |
| Day 7| Special subject seminar | Written and oral examination |

Table 4 Courses for concrete production and mechanical maintenance (28hrs)

<table>
<thead>
<tr>
<th>Unit</th>
<th>Courses</th>
</tr>
</thead>
</table>
| 1    | 1.1 Concrete component material (1hr)
|      | 1.2 Properties of fresh concrete (2hrs)
|      | 1.3 Properties of harden concrete (2hrs) |
| 2    | 2.1 Concrete production (4hrs)
|      | 2.2 Concrete construction (2hrs) |
| 3    | Aggregate test, testing of fresh concrete, Cylinder test (3hrs) |
| 4    | 4.1 Basic electrical and auto control operation theory (3hrs)
|      | 4.2 Mechanical equipment maintenance and calibration (7hrs) |
| 5    | 5.1 Ready mix plant visit and discussion (3hrs)
<p>|      | 5.2 Oral examination (1hr) |</p>
<table>
<thead>
<tr>
<th>Unit</th>
<th>Courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.1 Concrete component material (1hr)</td>
</tr>
<tr>
<td></td>
<td>1.2 Properties of fresh concrete (2hrs)</td>
</tr>
<tr>
<td></td>
<td>1.3 Properties of harden concrete (2hrs)</td>
</tr>
<tr>
<td>2</td>
<td>2.1 Concrete production (2hrs)</td>
</tr>
<tr>
<td></td>
<td>2.2 Concrete construction (1hrs)</td>
</tr>
<tr>
<td>3</td>
<td>3.1 Aggregate test (8hrs)</td>
</tr>
<tr>
<td></td>
<td>3.2 Test of fresh concrete (4hrs)</td>
</tr>
<tr>
<td></td>
<td>3.3 Test of harden concrete (3hrs)</td>
</tr>
<tr>
<td>4</td>
<td>4.1 Ready mix plant visit and discussion (3hrs)</td>
</tr>
<tr>
<td></td>
<td>5.2 Oral examination (1hr)</td>
</tr>
</tbody>
</table>
The Taiwan Strait

Suao

Toouchhen

Taipei

Taoyuan

Taipei-Ilan Expressway

The Second Freeway

Kaohsiung

Southern Cross-Island Expressway

Central Cross-Island Expressway

Hualien

Taitung

Tainan

Keelung

Taipei-Ilan Expressway Suao Extension

Southern Section of Eastern Expressway

Figure 1 The scheme of Taiwan Area Freeway Network