

# A Review of SCC Application in Taiwan

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## ABSTRACT

Self-Compaction Concrete (SCC) without any vibration during its placing was first applied on a three-span 90 meters length bridge of Expressway in Taiwan at 1999. After the successful of application, SCC consecutively used on buildings and bridges at different projects, and its quantity has accumulated to more than a million cube meters during past ten years. However, SCC mix design still based on the experience of engineer, physical properties of aggregate and type of binder material used, etc.. Due to the importance of flowing properties is higher than the compression strength of SCC, some mix design might use higher S/A ratio, lower coarse aggregate content and high quantity of binder to ensure its flowing ability. This kind of mixture will easily create segregation and shrinkage cracking on the surface or top layer of SCC. Therefore, optimization of the mix proportion of SCC and a verify program to ready-mix plant for its production ability become necessary. Air-voids appear on the surface of SCC after demolded was a special phenomenon of SCC compare to normal concrete that concrete placing skill need to modify compare to OPC. SCC mixture contents granulated blast furnace slag(GGBS) and fly ash(PFA) to replace cement up to 45~55% lead to become an ecological, sustainable material by reducing emission of CO<sub>2</sub> up to 200kg for per M<sup>3</sup> of SCC. SCC being more widely applied not only for the automation of concrete construction, also for its reducing the amount of cement used in concrete, as well as more durable than OPC.

Keywords: SCC, Concrete, Bridge

## 1. Introduction

After the year of 1999 Chi-Chi Earthquake, the earthquake design criterion for bridge had modified that the quantity of reinforcement in structural member has increased (Table 1) and more complex (Picture 1). Member with curved shape induced more difficulty in placing concrete. Concrete honeycomb and repaired become major problems. Concrete quality and reliability of structure can not be assured. Also, shortage of technicians and vibrating noise urge the concrete

technology need to improve (Picture 2). Actually, in underwater concreting, cast-in-place piles as well as continuous wall, no vibration being made. (Pictures 3 and 4)

SCC has good flowing ability that can pass through gaps between reinforcements and adequately fill the spaces in the mold without segregation become the material that can solved conditions such as member contents high quantity of rebar or member that can not being vibrated due to confined space. Although SCC without vibration, it still can gained high compression strength and long-term durability of concrete. Since 1999, Taiwan Area National Expressway Engineering Bureau (TANEEB) has started the research, evaluation and application of SCC in bridges step by step until now. SCC has successfully applied in bridge foundation, column and superstructure. In this paper, SCC projects will be introduced; specification, quality control tests, mix proportion, properties as well as construction practices learned will be discussed.

Table 1 Quantity of reinforcement range at different member of different traffic lanes of expressway unit:Kg/m<sup>3</sup>

Member Type	Foundation	Column	Box Beam
3 Lanes	110-160	130-390	140-180
2 Lanes	87-121	358-490	214-216
2 Lanes	68-102	161-432	151 - 363



Picture 1 Dense Rebars at column      Picture 2 Labor cost and noise of vibration



Picture 3 Concreting under water



Picture 4 Cast-in-place pile

## 2. SCC Projects

### 2.1 Wu-Ze Bridge (1999-2001)

Wu-Ze Bridge is the first bridge in Taiwan that applied SCC. This is a pass-through bridge located at the Wu-Ze interchange connection road (sited at central part of Taiwan) of the Second Expressway with a total length of 90 meters. It was designed separately for two directions (Northbound and Southbound). The width of a bridge deck for each direction was 15.15 meters, and the superstructure was a single-cell prestressed concrete box beam; the depth of the beam was 2.2 meters, and the compression strength of concrete at the superstructure and the column of the bridge in south and north directions were 350Kgf/cm<sup>2</sup> and 420Kgf/cm<sup>2</sup>, respectively. However, during the construction, the design strength of concrete at the northbound bridge was 560Kgf/cm<sup>2</sup>. The northbound bridge used SCC and southbound bridge used OPC to construct. The column of the bridge was designed to be a single column structures with cap beam and rectangular foundation. Figure 1 shows the front view of the bridge, Figure 2 shows the cross-section of superstructure and Figure 3 shows the cross-section and front view of the column. Picture 5 was the outlook of the Wu-Ze Bridge. Designed parameters of the bridge are listed below. [1]

- Concrete : Northbound superstructure  $f'_c=560\text{kgf/cm}^2$  (SCC) ;  
                     Southbound superstructure and column  $f'_c=350\text{kgf/cm}^2$  (OPC);  
                     Foundation  $f'_c=280\text{kgf/cm}^2$
- Reinforcement :  $f_y=4200\text{kgf/cm}^2$
- Same amount of prestressed steel wire strand in superstructure at each bound
- Southbound column size at the bottom part was 280×280cm, Northbound was 240×280cm (around 81% of the southbound cross-section, the quantity of concrete used was 81% of the southbound)



## 2.2 Expressway No.6 Project (2005-2009)

Expressway No.6 started from Wu-Fong interchange of Expressway No.3 (Picture 6) and ended at Pu-Li interchange (Picture 7) with total length of 37.6km. In this road, the structural types including 4.2km of tunnels, 26.4km of bridges and 7.0km of embankment. Totally, 39 bridges will be constructed; among those bridge spans, the longest one is 150 meters, and 69 spans are more than 100 meters (Pictures 8-11). Construction methods of superstructure including advanced shoring method, cast-in-place cantilever method, cast-in-place span by span method and steel box beam hanging method, etc. The construction started from 2005 and completed at the end of 2009.



Picture 6 Start point of Expr. No.6



Picture 7 End point of Expr.No.6



Picture 8 Ai-Lan Bridge



Picture 9 Wu-See Viaduct



Picture 10 Kao-Sen Interchange Viaduct



Picture 11 Kao-Sen Interchange

The height of columns between 10 to 65 meters, and cross section shapes of column are circular, rectangular, and octagonal, etc. (Pictures 12-15). Some columns are hollow. Total quantity of SCC used in columns was 29,900m<sup>3</sup> for compression design strength 420Kg/cm<sup>2</sup> and 167,600 m<sup>3</sup> for compression design strength 350Kg/cm<sup>2</sup>.



Picture 12 Circular shape column



Picture 13 Cone shape column



Picture 14 Polygonal type column



Picture 15 V-Shape Column

### 2.3 First Expressway Foundation Retrofit Project (2009-2010)

In order to increase the resisting ability of earthquake, existing 1<sup>st</sup> expressway being excavated its original foundation and enlarged the width and thickness of foundation. SCC was used to fill the space under existing concrete foundation. (Pictures 16-18)



Picture 16 place reinforcement



Picture 17 Placing SCC



Picture 18 Completion

### 2.4 Taichung City Ring Road Project (2008-2011)

Bridge column constructed via precast segment to combine as a member was design to use SCC in these segments (Figures 4 and 5) applied in Taichung City Ring Road Project. (Picture 19) The quantity of SCC for segments is 3,310m<sup>3</sup>, but the whole project totally applied 150,000m<sup>3</sup> SCC with compression strength 350 kgf/cm<sup>2</sup> and 420 kgf/cm<sup>2</sup> for other cast-in-place columns.

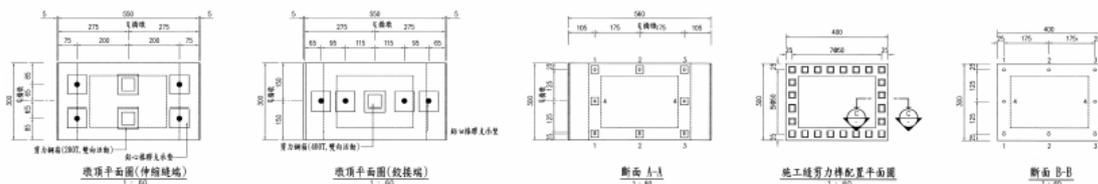


Figure 4 Cross-section of precast segment for column at different levels

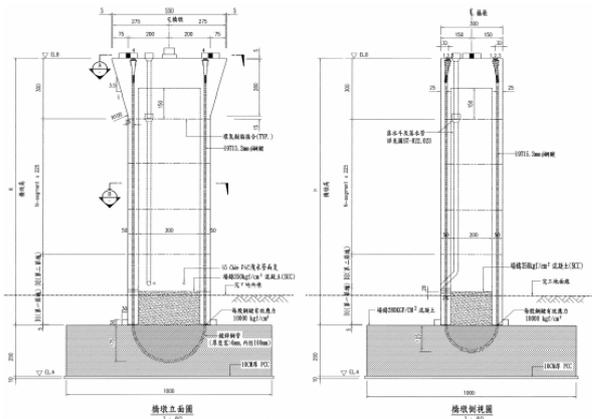


Figure 5 Details of precast segment column



Picture 19 Erected of column

### 2.5 Da-Pan Bridge(2008-2011)

The bridge with a sailboat shape (Figure 6) applied 7,200m<sup>3</sup> SCC on the pylon has the design strength 420 kgf/cm<sup>2</sup>, 7,100m<sup>3</sup> SCC on other piers has the design strength 350 kgf/cm<sup>2</sup>.



Figure 6 Da-Pan Bridge applied SCC on pylon and piers

### 2.6 BaLi-WuGu Freeway Project ((2005-2009)

BaLi-WuGu Freeway is a connecting freeway of Taipei City to Taipei Harbor with a four lanes freeway with two lanes at each direction. Total length of 11km. SCC used on columns to 41,000m<sup>3</sup>. (Picture 20)



Picture 20 SCC on columns of BaLi-WuGu Freeway

### 2.7 1<sup>st</sup> Freeway Wu-Yang Section Broaden Project (2010-2012)

This project was a 2 lanes widen at each direction (northbound and southbound) by viaduct (Figure 21 and 22) with 37 km length. 200,000 m<sup>3</sup> of SCC applied on column and High Performance Concrete (HPC) for all the foundation and superstructure in this project.



Figure 21 Double deck Bridge



Figure 22 Bridge type of Wu-Yang section

### 2.8 12,000Psi SCC for Airport MRT Taipei Station

Tao-Yuan International Airport MRT to Taipei Station project, the Taipei station will be a 76 floors high-rise building and its steel structure column will fill in SCC with 12,000 Psi strength. The SCC trial mix and pumping test just completed September 2010.

## 3. SCC Specification

The ability of concrete with self-compacting is related to quantity and spacing of reinforcement. Self-compacting of concrete can be verified by slump-flow test, V shape flowing time test and U-shape (Box-shape) filling height test. The specification of SCC in different reinforcement details are shown in Table 2. Concrete reached values as shown in Table 2 can be regarded as self-compacting model without any vibration during placing.

Table 2 Target values of SCC test [2]

SCC Grade		Grade 1	Grade 2	Grade 3
Reinforcement details	Rebar Spacing, Min. (mm)	35-60	60-200	200 以上
	Reinforcement (kg/m <sup>3</sup> )	>350	100-350	<100
Flow ability	Slump flow (mm)	650-750	600-700	500-650
Rebar spacing passing test	U shape (box shape) filling height (mm)	>300 (Obstacle R1)	>300 (Obstacle R2)	>300 (No obstacle)
Segregation resistance	V shape flowing time (sec)	10-25	7-20	7-20
	Reach 500mm slump flow time (sec)	5-20	3-15	3-15

#### 4. Laboratory Control Tests

Since SCC characteristics is on the workability, how to evaluate the performance become essential. As recommended by Table 2, three different tests were used as listed below.

##### 4.1 Slump flow test

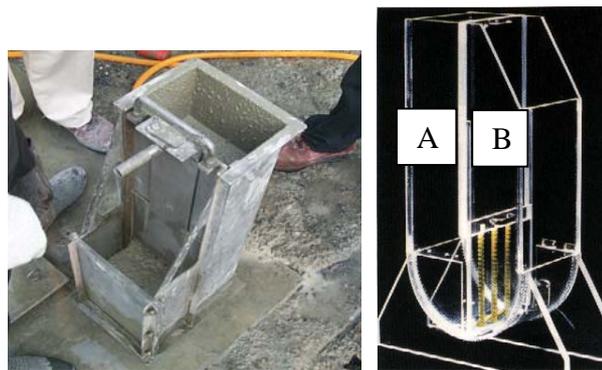
The slump flow test uses the same equipment and method as the slump test does. During the concrete stops flowing, its diameter is then measured. The averaged diameter obtained from the cross section is shown in picture 23. During the test, 500mm flowing time is measured in the slump flowing test when the slump flow reaches 500mm.



Picture 23 Slump flow measure method

##### 4.2 U shape or box shape filling height test

U shape (box shape) apparatus is divided into two cells; left cell (A) and right cell (B) are divided by a moveable gate. In the moveable gate position, there are several bars being an obstacle (Picture 24). Obstacle R1 is composed of five D10 deform bars, and R2 is composed of three D13 deform bars. The measuring method is to close the gate, put the concrete into cell A; when it reach the top, pull up the gate, and the concrete will flow through the obstacle to cell B until the concrete stop flowing, then the concrete height can be measured at cell B.



Picture 24 U-Shape Filling Test (R2 U-Shape)

##### 4.3 V shape flowing time test

Close the V shape steel bottom gate, fill in with concrete from the top and leveling, open the gate after 10 seconds and record the time taken as soon as concrete all

flow out from the V shape. Also evaluate if any concrete stick on the shape (Picture 25).



Picture 25 V shape flowing time test

### **5. Field Quality Assurance Tests**

SCC is a material that need special care for its mixture and workability performance stability, field test will be necessity. However, during SCC placing, SCC experiments took time that will delay the placing speed. From on site experience, the better way will be using slump flow test to evaluate first, then applied U-shape test when necessary. The decision will depend on the judgment of supervisor on site.

### **6. SCC Mix Proportion and Placing**

SCC can passing through reinforcements based on its mix proportion has limited content of coarse aggregate, low water-powder ration, high binder content, high dosage of water reducing agent and Sand/Aggregate(S/A) ratio that create compatible of deformability & viscosity of concrete. The mix design procedure suggested as follow:

1. Referred to Table 2, according to the quantity of reinforcement and spacing between reinforcement decided the grade of SCC and its target values of workability, for member that planning to cast concrete;.
2. Select the w/b ratio of mixture;
3. Select the coarse aggregate content by  $m^3/m^3$  concrete;
4. Select the sand/aggregate ratio;
5. Select the content of binder(cement, GGBS, PFA);
6. Trial mix and modified the mix proportion;
7. plant mix ;
8. Mock-up test, if necessary.

Table 3 compared the SCC mix proportion between different stage projects, it will be easy to find that mineral admixtures (GGBS and PFA) were used at the latest project (Wu-Yang Widen Project). GGBS and PFA both replaced cement up to 45%, including 10% of PFA. Total cementitious keep at  $450 \text{ kg/m}^3$  was the minimum amount that ready mix plant suggested.

In order to know the production capacity of the ready mix plant, the fresh SCC uniformity and stability, placing speed control, form work bracing behavior, effect of slope, training of technicians and curing time decision, etc. Several structures placing as well as a mock-up test were preceded before casting the bridge members. Also ready mix plant needs to verify its product (SCC) can remain its flowing properties for duration up to 90 minutes (Figures 7)

Table 3 Comparison the SCC proportion at different stages of application

Project	Cement	GGBS	PFA	Total Binder	w/b	S/A	f <sub>c</sub> Mpa
Wu-Ze (1999-2001)	320	183	93	596	0.32	51	72
Freeway No.6 (2005-2009)	264	216	-	480	0.36	51	76
Da-Pang (2008-2011)	525*	-	-	525	0.33	51	48
Taichung (2008-2011)	256	209	-	465	0.40	51	59
Wu-Yang (2010-2012)	250	155	45	450	0.39	54	62

\*:Slag cement

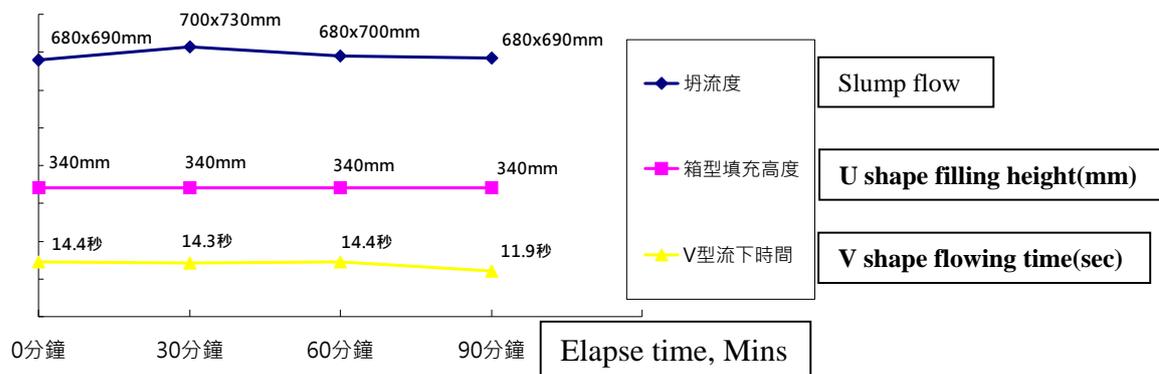


Figure 7 SCC performance test after elapse time 90 minutes

## 7. SCC Properties

**Compression strength**, from the above results, most of SCC has a higher strength than its mix design expected, it also much higher than the same w/c ratio of normal concrete. The phenomenon could be explained that SCC has a low water/binder ratio and high content of binder material. Without using non-reactive

powder to replace binder, SCC will still reach high strength than expected.

**Elastic Modulus**, SCC has a lower modulus compared with OPC and its value average reached to 80-90% of OPC value. Reasons coming mostly from higher sand/aggregate ratio, higher binder content, smaller of the maximum coarse aggregate size.

**Shrinkage**, figure 8 showed OPC) and SCC drying shrinkage strain with design strength( $f'c$ )  $350\text{kg/cm}^2$  after water curing 28 days, the difference seems not very obviously. [3]

**Creep**, figure 9 showed  $f'c$   $350\text{ kg/cm}^2$  OPC and SCC after 28 days water curing and preceded the creep test at a standard curing environment ( $23^\circ\text{C}$ , R.H. 100%) until 1000 days. Results indicated that SCC has higher creep, it was due to SCC used more binder than OPC, also its elastic modulus is lower. [3]

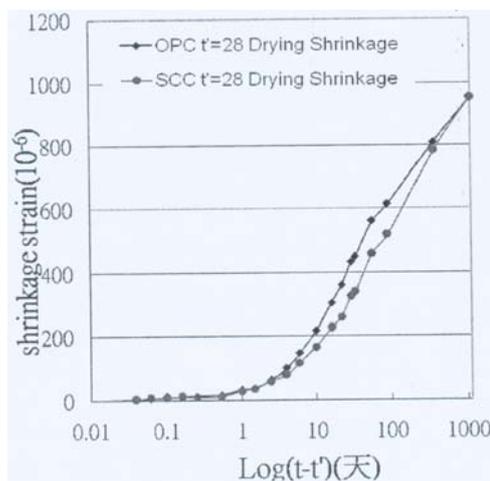


Figure 8 Shrinkage of OPC and SCC

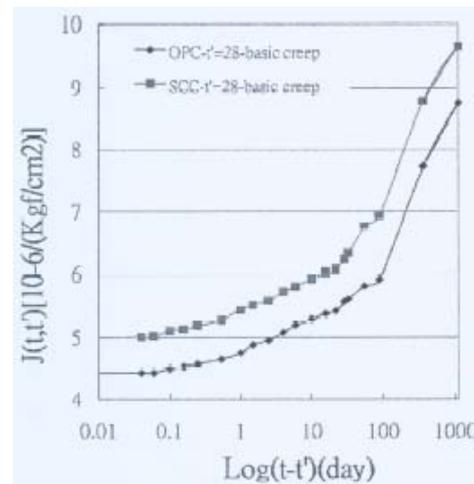


Figure 9 Basic creep of OPC and SCC

## 8. Some Lessons Learned

Results and comments are obtained from mix design and construction cases:

1. Fine aggregate fineness modulus suggest controlled between 2.7~2.8.
2. Content of coarse aggregate and the maximum size of coarse should be control to prevent the blocking in U-shape test.(Picture 26)
3. SCC is very sensitive to the amount of water and dosage of water reducing agent, without accurate control of quantity, slump flow will not be stable (Picture 27) even could be segregation (picture 28), or maybe too cohesive that spent long time to flow through V-shape (Picture 29). Therefore, the total water content of fine aggregate should be controlled (<4%) with less variation before pouring into mixer.
4. In order to have good uniformity, the mixing time of SCC will be longer than OPC that decreased the production capacity of ready mix plant.

Therefore, the mixing time should be controlled to less than 90 seconds.

5. SCC has high flow ability, during placing should beware of the lateral force effect on the form. According to the results from construction, if the bracing at the bottom of form is insufficient, SCC will pour off from bottom and induce formwork exploded, or tie bar broken created the deformation of form. Its better to use enough stiffness steel system formwork, also the formwork design should be permitted before placing concrete.
6. In order to reduce the air voids on surface concrete after demolded (Picture 30), the placing rate, pouring position and flowing distance of SCC in the structural members need to evaluate before the placing work.
7. SCC use low water/binder ratio and high content of binder than OPC, if the curing hadn't applied in time after placing, concrete surface would easily created plastic shrinkage cracks. Therefore, a suitable time to cure the concrete is very important. Generally, curing started just after finished the placing or finishing.
8. SCC has the ability of self-leveling; structure with slope should add top form or decrease the flow ability of SCC.
9. Sometimes, the surface of concrete will have a higher content of mortar and less aggregate, it was a kind of segregation. When concrete hardened, water jet treatment on the surface should be done until aggregate was seen before new concrete placing on its surface again.



Picture 26 Blocking of SCC in U-shape test or in V-shape test



Picture 27 Slump flow difference between each batch



Picture 28 SCC segregation



Picture 29 Mixture too cohesive  
increase flowing time



Picture 30 SCC surface easy to create air void due to no vibration

## 9. Closing Remarks

SCC has high viscosity increase loading to mixer & pump line, high flowing ability increase lateral pressure to mold, sensitive to water that ease to segregate & no flowing, self-compacting properties need certain placing method, and low w/b ration need to water curing as early as possible. However, it also bring several benefits to concrete structure such as provide a variety of options during structural design, capable to place concrete in narrow space, automation of concreting, fewer labors and improve the working environment as well as increase the quality and reliability of concrete structure.

TANEEB has been applied SCC in its bridge projects for more than 10 years, the amount of SCC used being over 0.7 million cube meters. SCC has become a popular concrete material in concrete market, not only just for promoting the quality of concrete structure, but also for the sustainable development of the society.

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