Title:	**Prediction and Compensation of Column Shortening for Bitexco Financial Tower**
Authors:	Seongdeok Kang, Assistant Chief Engineer, Hyundai Architects & Engineers Associates Jaesung Choi, Chief Engineer, Hyundai Architects & Engineers Associates Hakseong Kim, Chief Engineer, Hyundai Architects & Engineers Associates Inki Kim, CEO, Hyundai Architects & Engineers Associates
Subject:	Structural Engineering
Keywords:	Concrete Core Structure
Publication Date:	2011
Original Publication:	CTBUH 2011 Seoul Conference
Paper Type:	1. Book chapter/Part chapter 2. Journal paper 3. **Conference proceeding** 4. Unpublished conference paper 5. Magazine article 6. Unpublished

MS04-13

Prediction and Compensation of Column Shortening for Bitexco Financial Tower

Seongdeok Kang[1], Jaesung Choi[2], Hakseong Kim[3], Inki Kim[4]

Assistant Chief Engineer[1], Structural Design Dept., Hyundai Architects & Engineers Associates, 140-2 Gye-dong, Jongno-gu, Seoul, Korea, sdkang@hda.co.kr
Chief Engineer[2], Structural Design Dept., Hyundai Architects & Engineers Associates, jschoi01@hda.co.kr
Chief Engineer[3], Engineering Division, Hyundai Architects & Engineers Associates, star@hda.co.kr
CEO[4], Hyundai Architects & Engineers Associates, ikk2537@hda.co.kr

Inki Kim, CEO of Hyundai Architects & Engineers Associates Co., Ltd.

Biography

Mr. Kim is a CEO of Hyundai Architects & Engineers Associates. Since 1977, he has been with the Hyundai Engineering & Construction and the Hyundai Architects & Engineers Associate. Mr. Kim has also leaded for various professional and academic projects in the areas of architectural design and structural engineering. He is experienced in both high-rise steel and concrete buildings. He is also leaded for research team in the area of high-rise building. Mr. Kim has over 34 years of structural engineering experience and is registered as a qualified architect and professional engineer in Korea. Recent high-rise building projects include the Bitexco Financial Tower in Vietnam, the International Finance Centre, and the Haeundae AID in Busan.

Abstract

The effects of column shortening, both elastic and inelastic, take on added significance need special consideration in design and construction. Axial shortening of columns due to long term creep and shrinkage is inevitable in tall reinforced concrete buildings. Therefore, a reasonable idea about the probable axial shortening could be important for construction engineers and project managers as well. A procedure is developed to predict the long-term deformations of reinforced columns and walls. The presentation will describe how to properly complete a Vietnam Bitexco Financial Tower Project. This is a commercial office development located in Hochiminh, Vietnam. The development is 258m(68 stories) in height and has three levels of basement. The tower is structurally composed of central reinforced concrete core and perimeter reinforced concrete columns connected in flat plate slab. The plan of the tower continually changes from oval to triangle at higher levels, so that some perimeter columns are declined in elevation and their locations also change in respective plans. Field measurement is performed to verify predicted axial shortening amounts and update compensation. Vibrating wire strain gauges are installed in selected vertical members before pouring concrete. Actual compressive strains of columns and walls due to load application and environmental effects are measured by vibrating wire strain gauges embedded in the member. Target members are selected when the results of initial axial shortening are available.

Keywords

Column shortening, Long term creep, Shrinkage, Field measurement, Long term deformation

1. Introduction

In high rise building serviceability aspects should take into account vertical shortening effects in the design stage. In this paper axial displacements are described as consequence of sequential loading phases and long term effects. Computer aided analysis has been carried out to deeply study the phenomena and main results have been reported in this document. In very high rise buildings, the cumulative vertical movements due to creep and shrinkage may cause distress in the structure and induce forces into horizontal elements especially in the upper regions of the building. As a consequence also the stress distribution in vertical structures can be different from design values. Since the differential shortening between core structure and peripheral columns causes unwanted slope to floor horizontal structures, compensations are needed to assure a proper final position for each slab within the building. Essentially, during the construction process, each of the story support undergoes *elastic shortening* due to construction sequential loading (that are the loads imposed by the upper levels as they are completed); in addition, columns begin to shrink from moisture loss and creep as a result of the time depending effects. Vietnam Bitexco Financial Tower Project is a commercial office development located in Hochiminh, Vietnam (Fig. 1-1). The development is 258m (68 stories) in height and has three levels of basement.
HYUNDAI Architects&Engineers Assoc. has been appointed to perform the Column Shortening Prediction to provide relevant information for differential shortening between vertical members as well as each level of the tower.

The scope of works to be undertaken by HYUNDAI A&E is as follows:

- Predict tentative values of axial shortening of core walls and perimeter columns based on structural drawings and analysis data, construction program, and environmental conditions;
- Provide the necessary preset values of core walls and perimeter columns based on tentative values of axial shortening;
- Perform creep and shrinkage tests on the concrete specimens to update the time-dependent material properties and enhance the accuracy of tentative values of axial shortening and corresponding presets;
- Perform on-site measurement for the axial shortening of selected core walls and columns to update the values of axial shortening and corresponding presets.

Fig. 1-1. Vietnam Bitexco Financial Tower

2. Analyses for Column Shortening

Structural drawings are the basis of the structural layouts, dimensional data of core walls and columns, rebar content, and the grades of concrete, steel, and rebar. Elastic Modulus of concrete is calculated from its strength according to ACI 318. Both the specific creep and ultimate shrinkage values are taken from ACI 209 and PCA report (Fintel, Mark, Ghosh, S. K, and Iyengar, Hal, Column Shortening in Tall Structures – Prediction and Compensation (EB108.01D), Portland Cement Association, 1986).

Members to be considered for the shortening prediction are selected by the following criteria:

- All perimeter columns are considered;
- Core walls are put together into 5 groups (W1~W5, see Fig. 2-1 below);

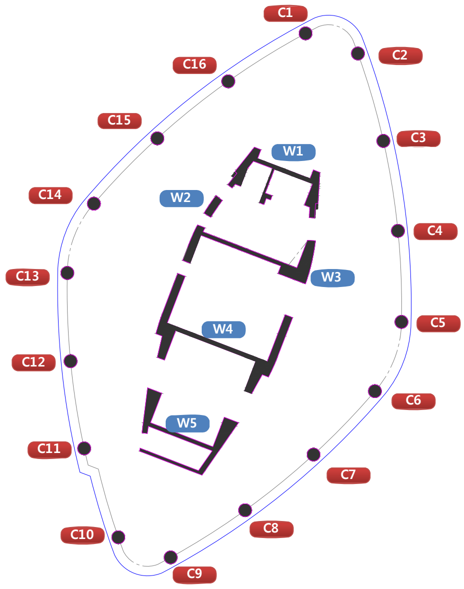

Fig. 2-1. Structural layouts

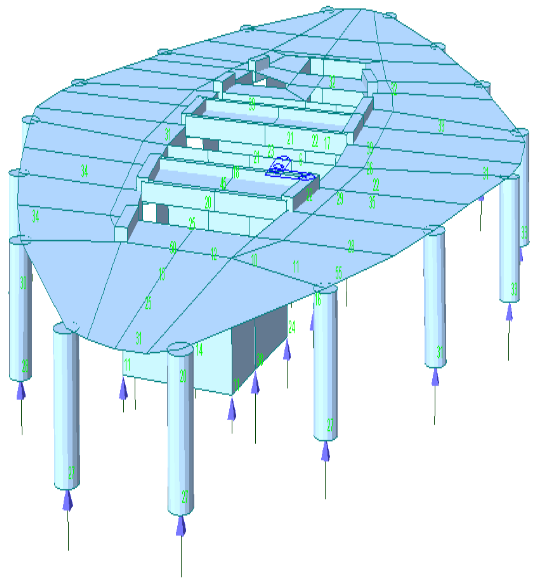

Fig. 2-2. Structural analysis model showing reactions at columns for Dead Load at 27th floor

All the design loadings are extracted by manipulating the ETABS model file. In addition to the existing 4 categories of loadings in the model, i.e. Dead Load (DL), Superimposed Dead Load (SDL), Façade, and Live Load (LL), DL is further classified according to the construction program as followings:

- Concrete column – calculated with member dimensions and concrete density
- Topping concrete on slab –slab weight

Load reduction factor for Live Load is assumed as 0.5, which is a sufficient value as compared with the minimum 0.4 for high-rise office buildings.
Since the column layout is different for every floor and core layout also changes several times, the distribution of floor load is recalculated for all stories from B3F to 68F by analyzing an isolated story model from the original ETABS model.
Creep and shrinkage components of axial shortening are influenced by the environmental condition such as relative humidity. The average value (71%) is used in the shortening prediction.
The sequential application of each floor load is input based on the internal construction schedule.

With regard to the shortening prediction the following criteria is adopted:

- Each floor load (DL) is applied on “Finish” date of the construction schedule;
- Façade Load is applied on “Finish” date of “Curtain Wall Unit” work schedule;
- LL is applied, which is 668 days after the concrete for B3F core walls and B2F core slabs are cast.

Total shortenings of core walls at top level are predicted from 80mm to 130mm. Total shortenings of columns are produced from 85mm to 160mm. These predicted values are well accordant with the values calculated by LERA (refer to structural drawings No.S-020). The SUBTO shortening after the installation of slabs are used to evaluate the differential shortening between adjacent members. Differential shortenings between core walls and columns and between adjacent columns are predicted within allowable tolerances (20mm, refer to Specification Sec. 03 30 00-1.6B) except C8, C9 columns. Relatively large SUBTO shortening at C8, C9 columns are occurred by helipad loads. Maximum differential shortening (74mm) are developed between

C8 column and W5 at 47th floor. Core walls and perimeter columns except C8, C9 columns are well within the allowable tolerance. Therefore, presets are only required for C8, C9 columns to have horizontal floors within allowable tolerance.

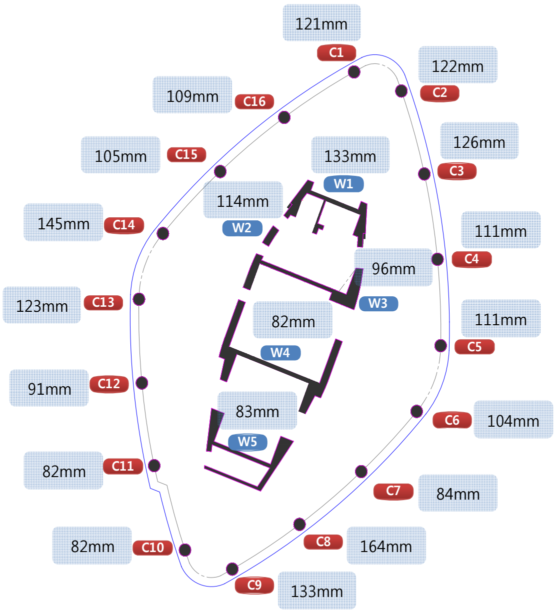

Fig. 2-3. Distribution of absolute shortenings

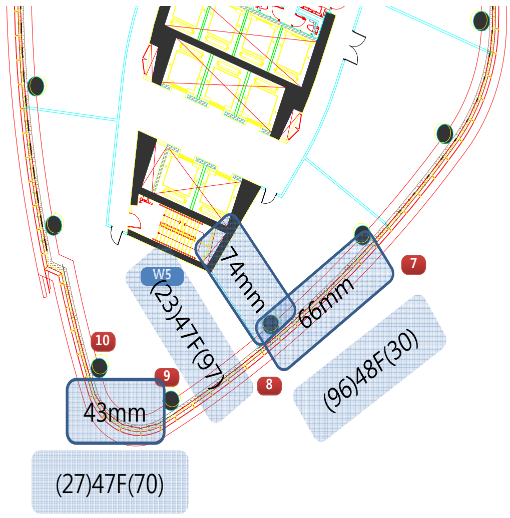

Fig. 2-4. Differential shortenings at the perimeter at top levels of each member of C8, C9 columns

3. Material Test

Specimens poured in the vertical members were made at the construction site. These were delivered at the laboratory in Korea with the moisture curing cover. The specimens were moist-cured for 28 days, followed by Elastic Modulus and cylinder strength test. Three creep specimens were under 30% of ultimate cylinder strength for more than three months in the constant temperature and humidity room (20±2℃, 60%). Shrinkage test specimens were kept in the same environment as the creep test specimens without any loading. Data readings from the strain gauges were recorded with constant interval (one time a day) during three months. Nonlinear regression analysis of the test data is performed using MathCAD to find the values for Specific Creep and Ultimate Shrinkage.
Concrete strain gauges were attached on the side surface of the cylinders in the middle and the obtained data were averaged in doing nonlinear regression analysis. Manual hydraulic jack with appropriate capacity was used to apply constant load under the spring-type creep test machine. The applied load in the creep test was monitored and the relaxation in the load should be recovered to the recorded value at the time of data readings.

Table 3-1. Test Results

	Initial analysis			**Test results**		
Concrete strengths	68MPa	30MPa	40MPa	67MPa 56MPa	40MPa	54MPa
Specific creep	0.40E-06	0.91E-06	0.69E-06	0.34E-06 0.45E-06	0.75E-06	0.84E-06

Ultimate shrinkage	750E-06	750E-06	750E-06	290E-06 456E-06	713E-06	1000E-06

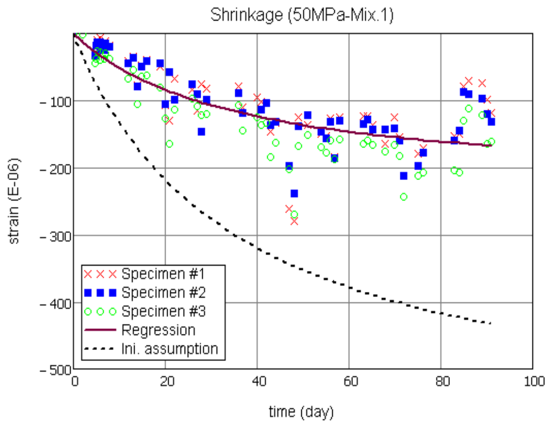

Fig. 3-1. Time-dependent shrinkage of 50MPa-mixture 1

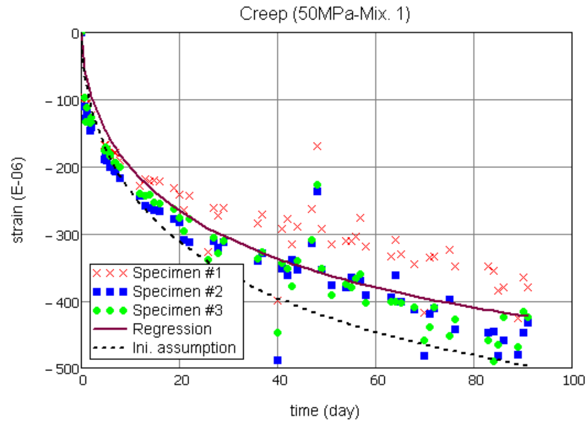

Fig.3-2. Time-dependent creep of 50MPa-mixture 1

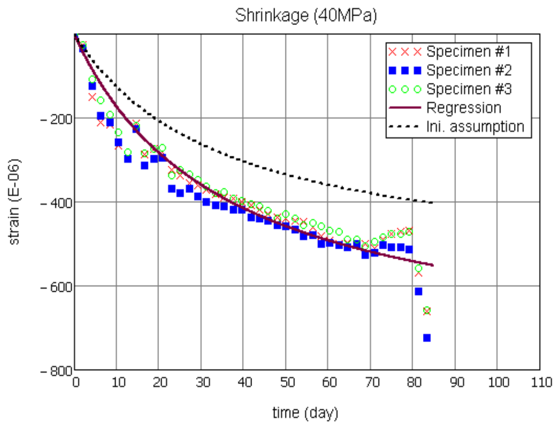

Fig. 3-3. Time-dependent shrinkage of 40MPa

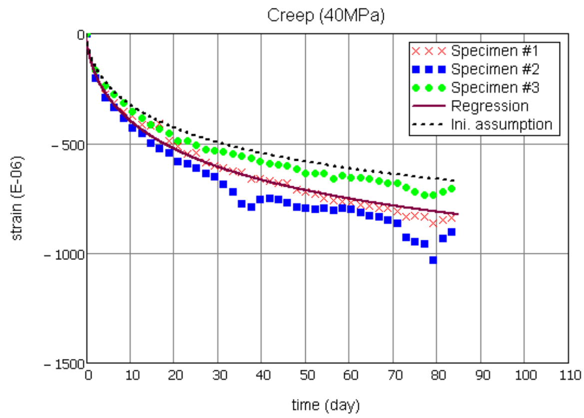

Fig.3-4. Time-dependent creep of 40MPa

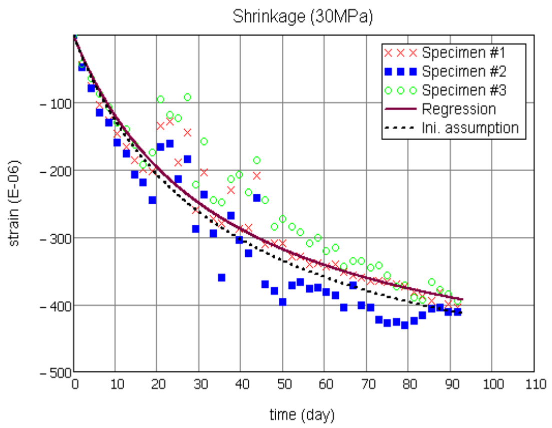

Fig. 3-5. Time-dependent shrinkage of 30MPa

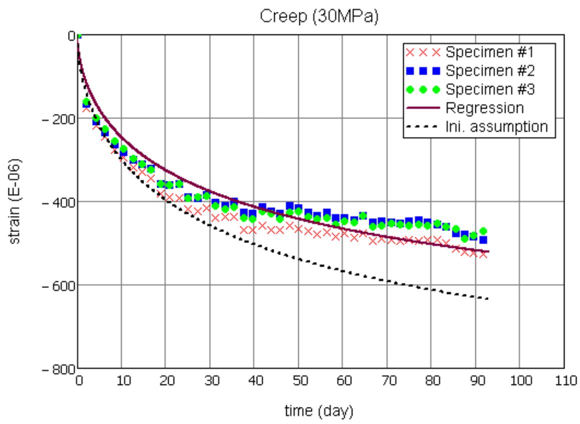

Fig.3-6. Time-dependent creep of 40MPa

4. Field Measurement

Field measurement is performed to verify predicted axial shortening amounts and update compensation. Vibrating wire strain gauges are installed in selected vertical members before pouring concrete. Actual compressive strains of columns and walls due to load application and environmental effects are measured by vibrating wire strain gauges embedded in the member. Target members are selected when the results of initial Axial Shortening are available.

The preferred levels to be measured are 4th Floor (the lowest level possible where the shortening from all the following load applications can be recorded), 35th Floor (different core concrete strength), and 49th Floor (the last oval level, above which the shape of plan becomes triangular). 2 strain gauges moved from 49th floor were installed on 4th floor slab below C10, C16 columns. The influence of 35MPa slab between 50MPa columns will be found from measurement results.

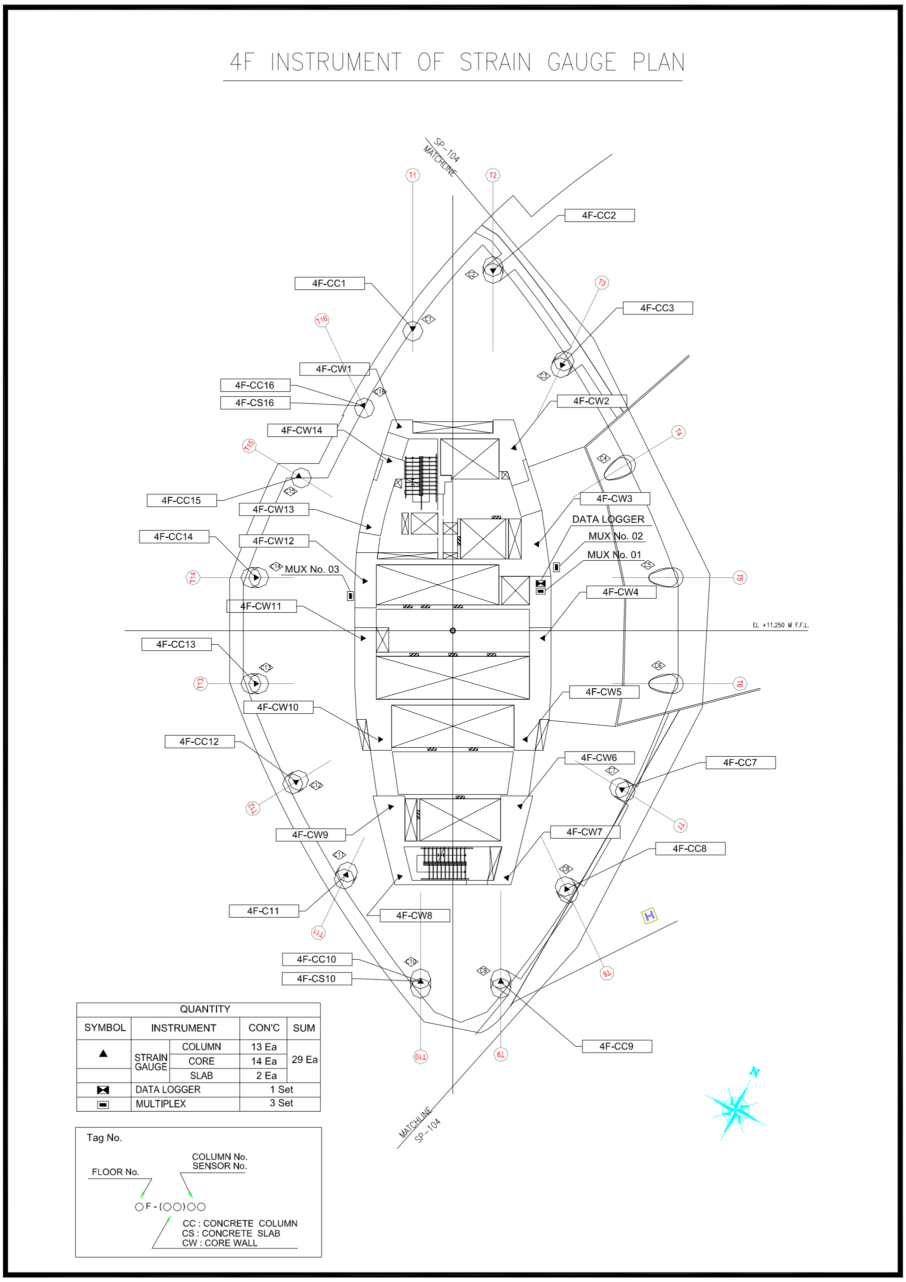

Fig.4-1. Installation plan of strain gauge (4F)

5. Conclusions

To predict axial shortenings of core walls and columns in Vietnam Bitexco Financial Tower, analysis, material test, and field measurement were performed. The results of works are summarized as followings.

In analysis, differential shortenings between core walls and columns and between adjacent columns were predicted within allowable tolerances (20mm, refer to Specification Sec. 03 30 00-1.6B) except C8, C9, and C13, C14 columns. Relatively large SUBTO shortening at C8, C9 columns were occurred by helipad loads. Therefore, presets are only suggested for C8, C9, and C13, C14 columns.

In material tests, 50MPa (two mixtures), 40MPa, and 30MPa concrete were tested to find 28days strength and the values for Specific Creep and Ultimate Shrinkage. Test results were used in 1st and 2nd re-analysis.

In field measurements, the shortening curves of predicted and measured values show the similar trend except C1, C13, and C16 at 4th floor. As considering neighboring members and measurement results of slabs, measured value of C1, C13, and C16 seem abnormal. Maybe there were locally mechanical problems in gauges. Based on the measurement results of same members in 35th and 49th floors, creditability of these values were low. The shortening values of C8 and C9 columns by helipad loads (deck slab and screed) were properly considered in predicted values. Based on the comparison results, it can be said that measured values are relatively consistent with predicted values. Therefore behavior of shortenings for this tower could properly predicted by analysis results.

As a final word for the shortenings, differential shortenings between core walls and columns and between adjacent columns will be within allowable tolerances on target day (1,000days after installation of the lowest basement floor) based on the results of analysis, compensations, and field measurement results.

References

Building Code Requirements for Reinforced Concrete, ACI 318-83 American Concrete Institute, Detroit, Mich., 1983.

M. Fintel, S.K. Ghosh, H. Iyengar, “Column Shortening in Tall Structures – Prediction and Compensation”, Portland Cement Association, pp.198.

ACI 209.2R-08, Guide for Modeling and Calculating Shrinkage and Creep in Hardened Concrete, 2008.

ACI Committee 318, Building Code Requirement for Structural Concrete (ACI 318-08), American Concrete Institute, Farmington Hills, MI, 2008.

Faber O. Plastic yield, shrinkage and other problems of concrete and their effects on design, Minutes of the Proc. of the Inst. of civil engineers, 225(1927), pp.27–73.

Bazant ZP, Prediction of concrete creep effects using age-adjusted effective modulus method, ACI Journal, 69(1972), pp.212–7.

D.Bast W, Terry RM, Parker L, Shanks S. Measured shortening and its effects in a Chicago high-rise building, Proceedings of the Third Forensic Engineering Congress, San Diego, CA, 2003.

Bazant ZP, Baweja S. Creep and shrinkage prediction model for analysis and design of concrete structure-model B3, Report No. 94-10/603c, Chicago, Northwestern University, 1995.

Jayasinghe MTR, Jayasena WMVPK. Effect of axial shortening of columns on design and construction of tall reinforced concrete buildings, Practice periodical on structural design and construction, 9(2004), pp.70–8.

ACI Committee 209. Prediction of creep, shrinkage, and temperature effect in concrete structures, Detroit, MI, 1992.