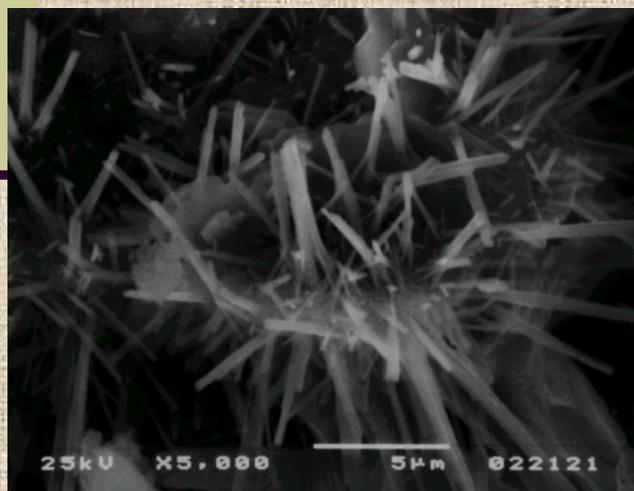


Oct. 14, 2008

***A METHOD OF SECTION DESIGN OF
CHEMICALLY PRE-STRESSED CONCRETE MEMBERS
USING A CONCEPT OF WORK-DONE
BY EXPANSIVE CONCRETE***



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Outline

In this approach,
We introduce method of evaluation for RC 'Pit'
using expansive concrete in disposal facilities low level radioactive waste

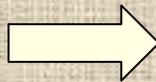
1. What is expansive additive?
How does expansive concrete works?
Application of expansive concrete in Japan
2. Evaluate of expansion for concrete members
3. Section analysis for expansive concrete
4. Controlling crack of concrete using expansive additive

What is Expansive Additive?

Expansive additives provide a means of offsetting volume change due to hardened shrinkage of concrete.
By using expansive additive, shrinkage of concrete can be compensated.

⇒ It can reduce risk of concrete cracking and decrease crack width.

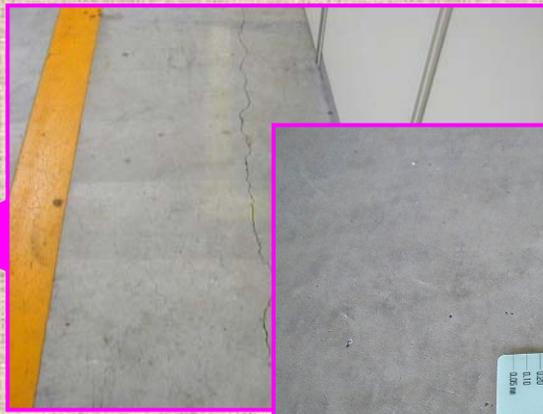
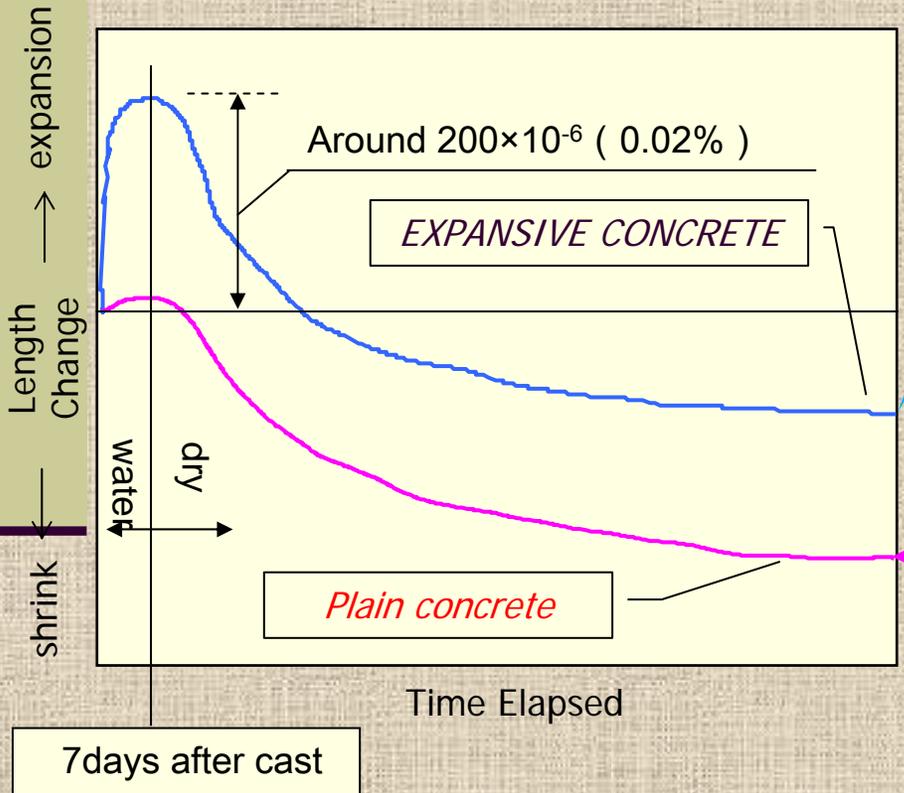
Expansive additive is used by mixing with concrete.
General dosage is 30kg/m³



Expansive additive is powder type supplementary comentitious material

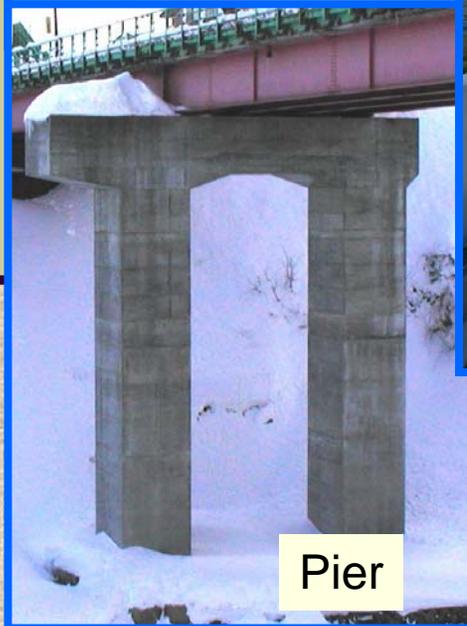
Length change of expansive concrete

Expansive concrete can compensate shrinkage
 ⇒ Crack and Crack Width should be reduced



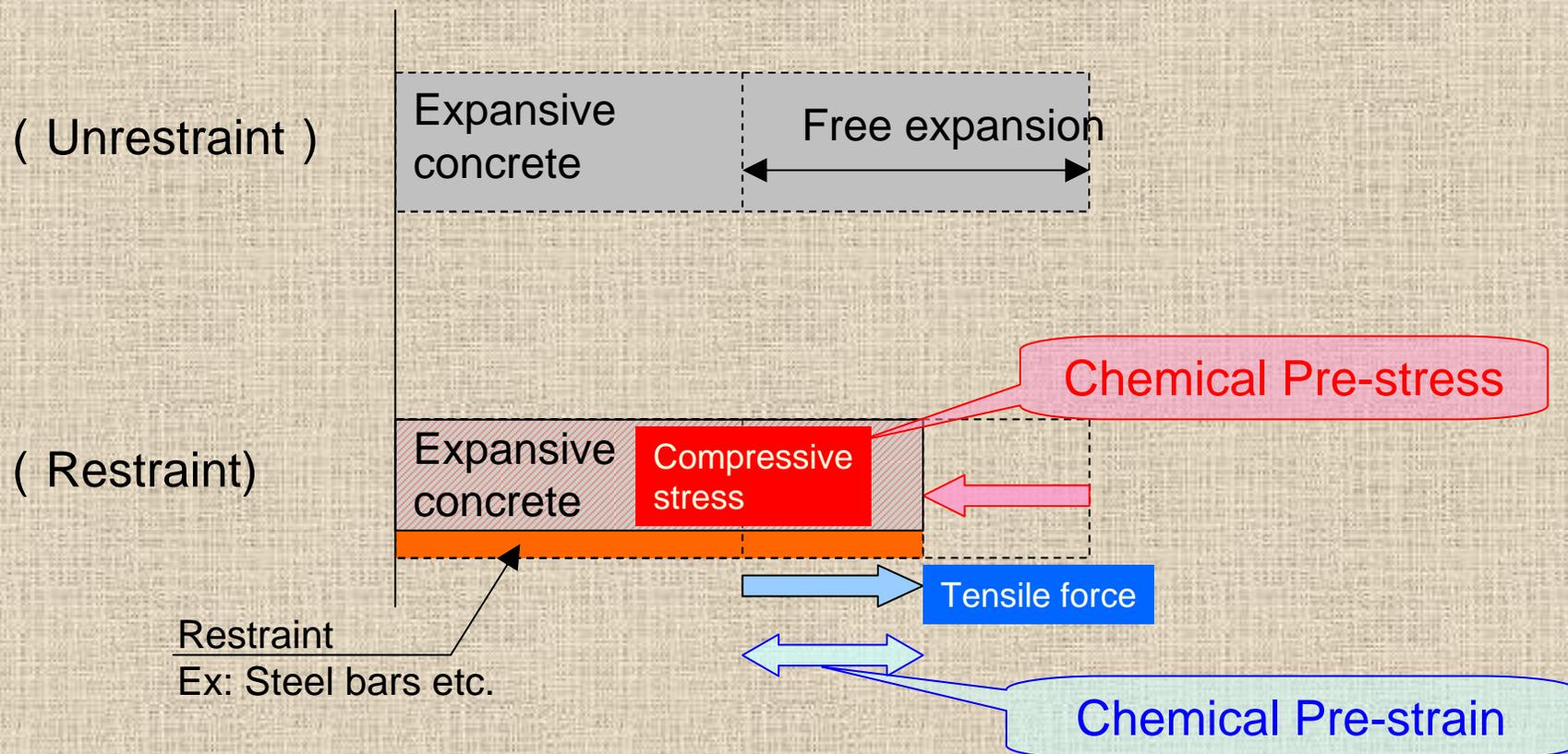
Expansive concrete compensate the shrinkage of concrete due to dryness

Use of expansive additive for concrete.



How does Expansive Concrete work?

Mechanism of reducing crack risk using Expansive Additive



This chemical pre-stress decreases cracking of concrete like mechanical Pre-stress.

Background

Basic design of the sub-surface disposal facilities for low activity waste is under planning in Japan.

And there are carrying out full-size specimen modeling for the facilities.

Basic required performance of this reinforced concrete 'pit'

⇒ It is to control crack width by mixing expansive additive.

So, it is important to evaluate physical properties of concrete with expansive additive.

This study proposes a limit state design method for expansive concrete members.

This presentation introduce,

a) Evaluation of the expansion

Method of estimating both chemical pre-strain and chemical pre-stress using *a concept of work done*.

b) Sectional Analysis

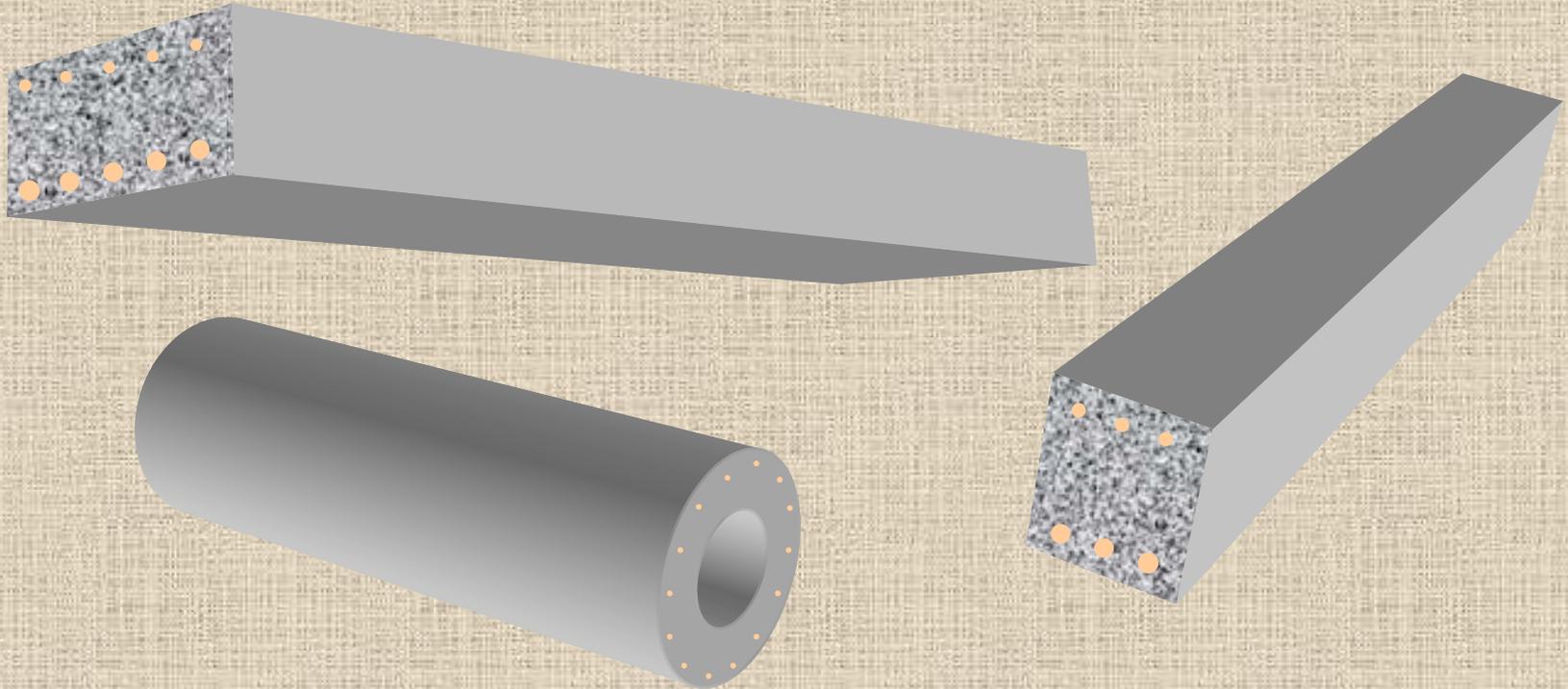
Method for calculating shrinkage reduction is explained using *a fiber model with the concept of work done*.

c) Controlling crack

Crack control of RC members using expansive concrete.

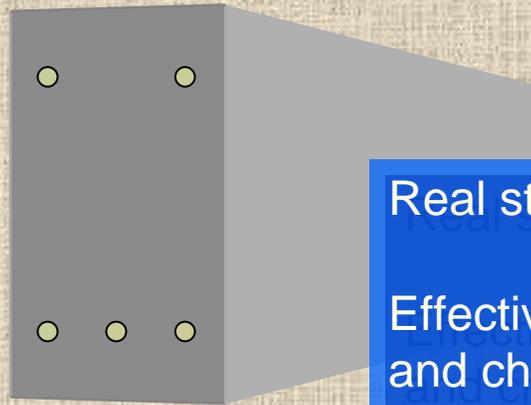
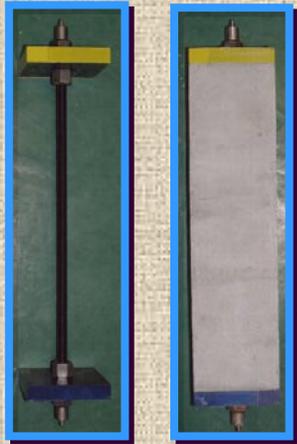
2. A Concept of Work done by expansive additive

Work Done of the concrete doesn't be affected by the degree of restraint
That is, for any structure, the work done is constant for the same expansive concrete.



A Concept of Work done by expansive additive

This concept can calculate both chemical pre-stress and chemical pre-strain of a RC member by using the expansive strain result of a standard specimen.



Real structures, RC members

Effective chemical pre-stress and chemical pre-strain

Standard specimen for length change test (JIS A6202)

Work done U :
$$U = \frac{1}{2} \sigma_c \cdot \varepsilon_s = \frac{1}{2} \rho \cdot E_s \cdot \varepsilon_s^2 = const.$$

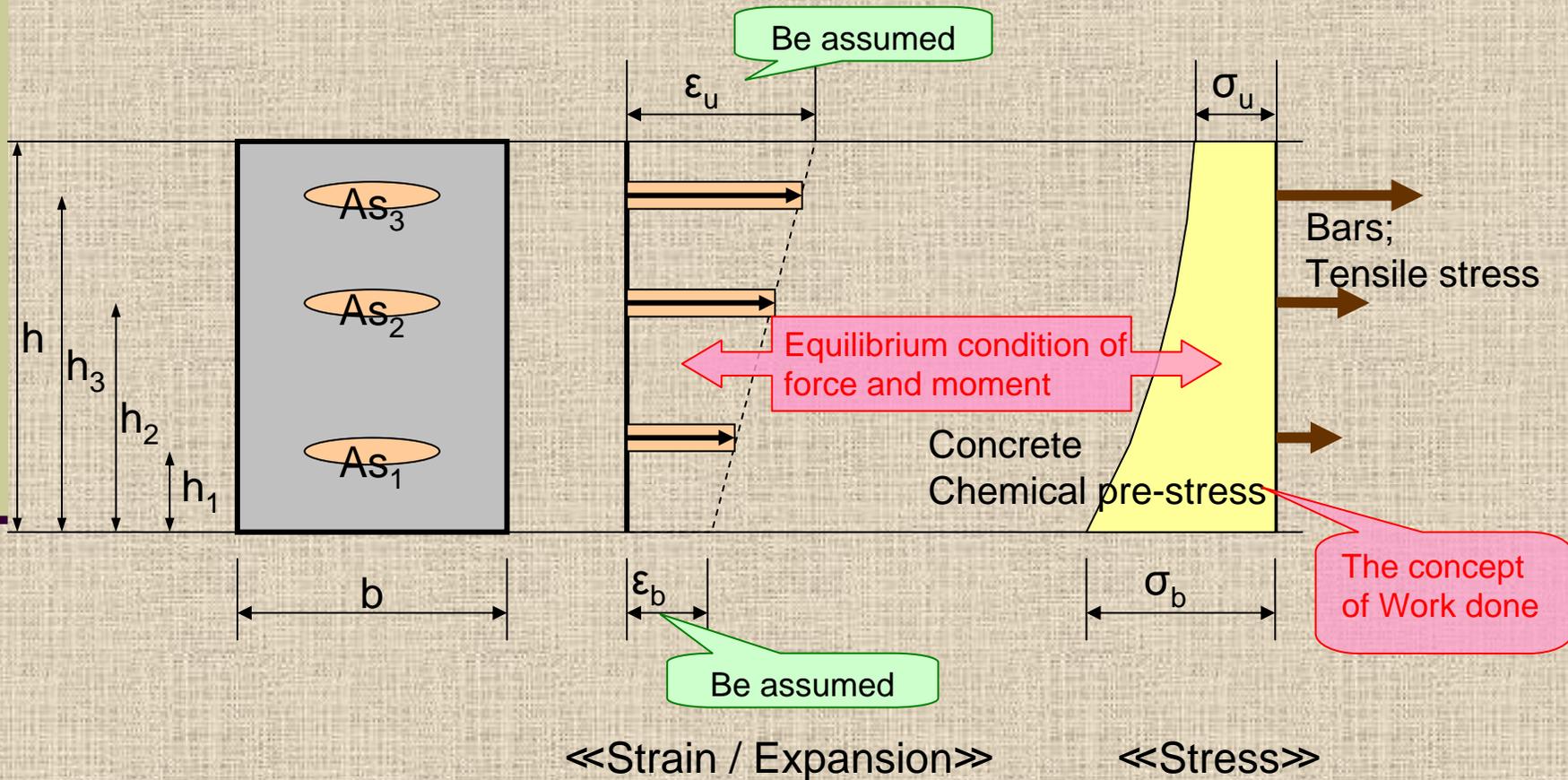
σ_c : Chemical pre-stress

ε_s : Chemical pre-strain

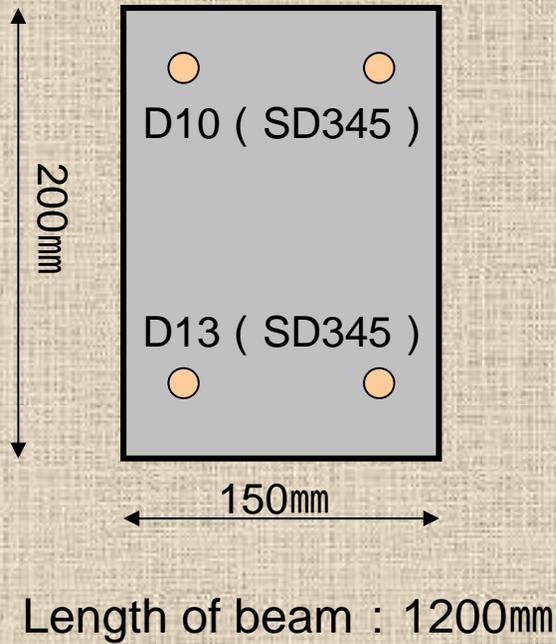
E_s : Young modules of bars (restraint)

ρ : steel rate

A method of estimating both chemical pre-stress and chemical pre-strain using the concept of work done

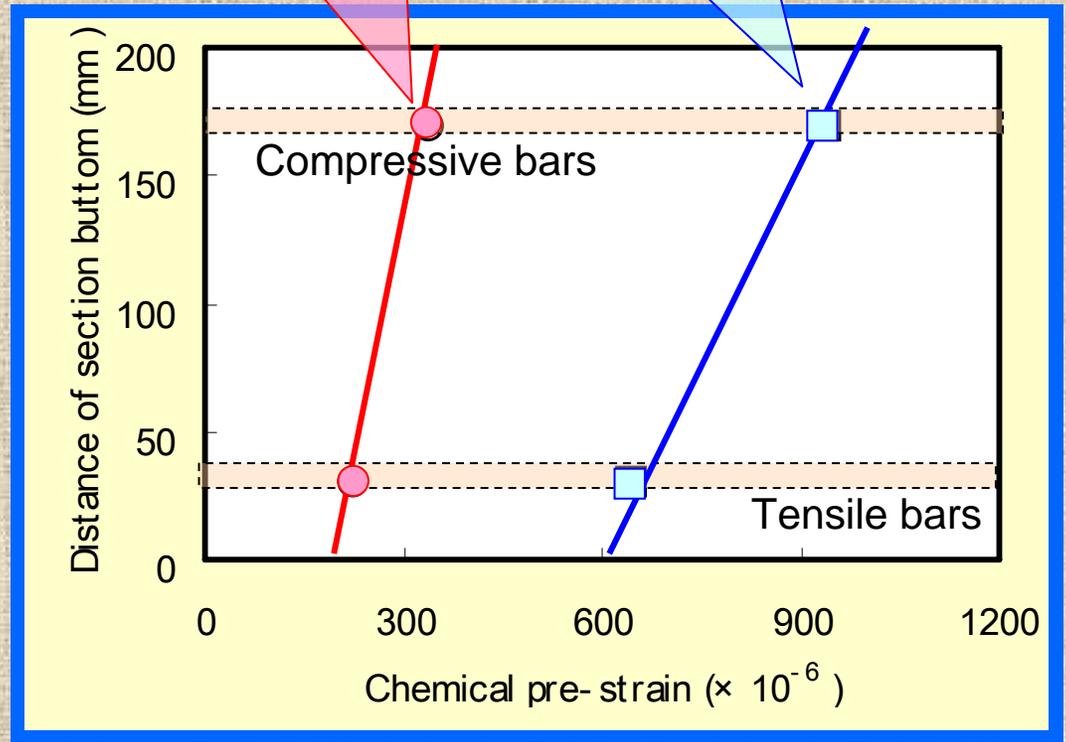


Example

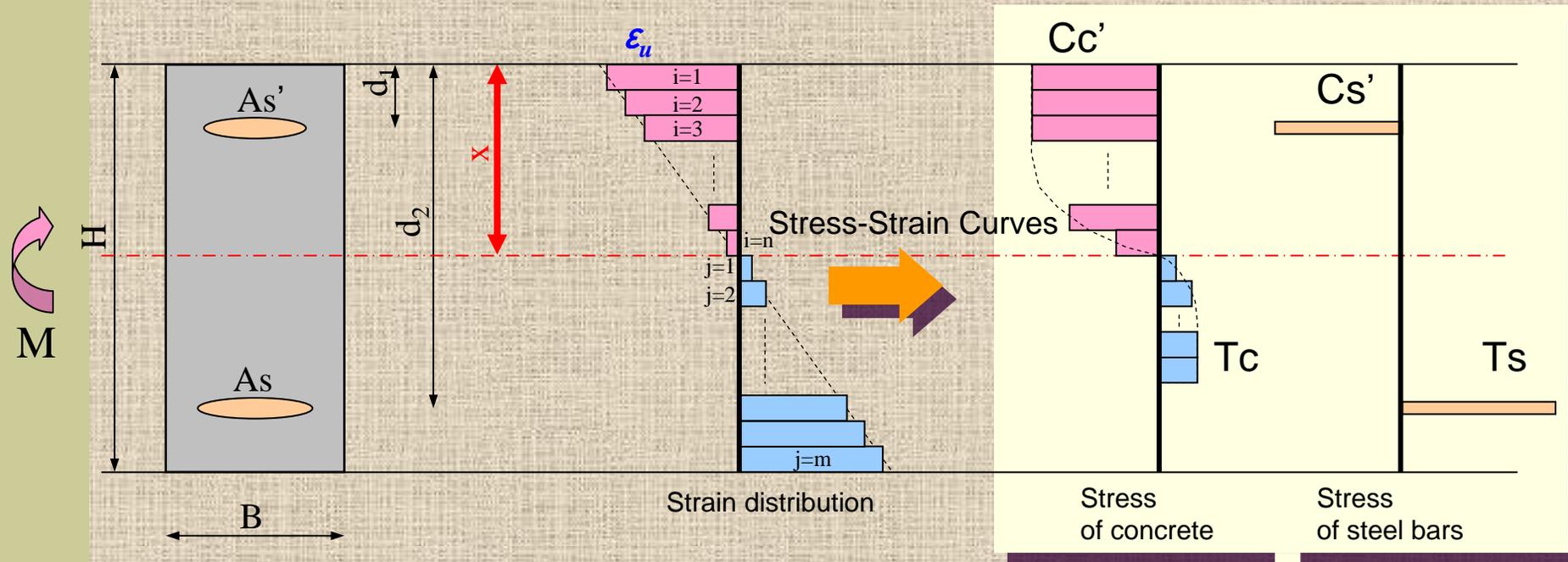


Expansive additive:
25kg/m³

Expansive additive
40kg/m³



3. Sectional Analysis by A Fiber Model with The concept of work done



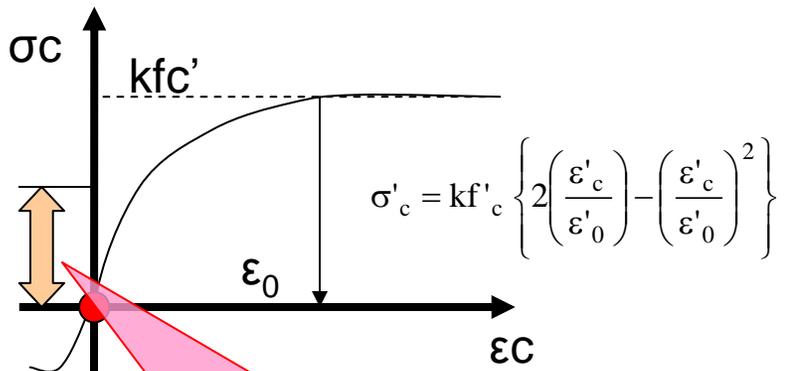
Equilibrium condition

$$\text{Force : } C_s' + C_c' = T_s + T_c$$

$$\text{Moment: } M = C_s' (d - d') + C_c' (d - y_c')$$

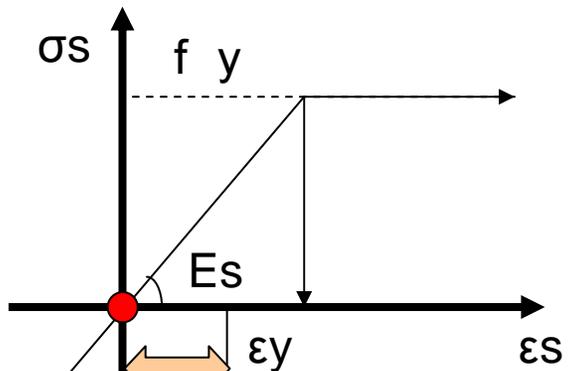
Stress Strain Curves

Concrete/ Expansive concrete



$$\sigma'_c = kf'_c \left\{ 2 \left(\frac{\epsilon'_c}{\epsilon'_0} \right) - \left(\frac{\epsilon'_c}{\epsilon'_0} \right)^2 \right\}$$

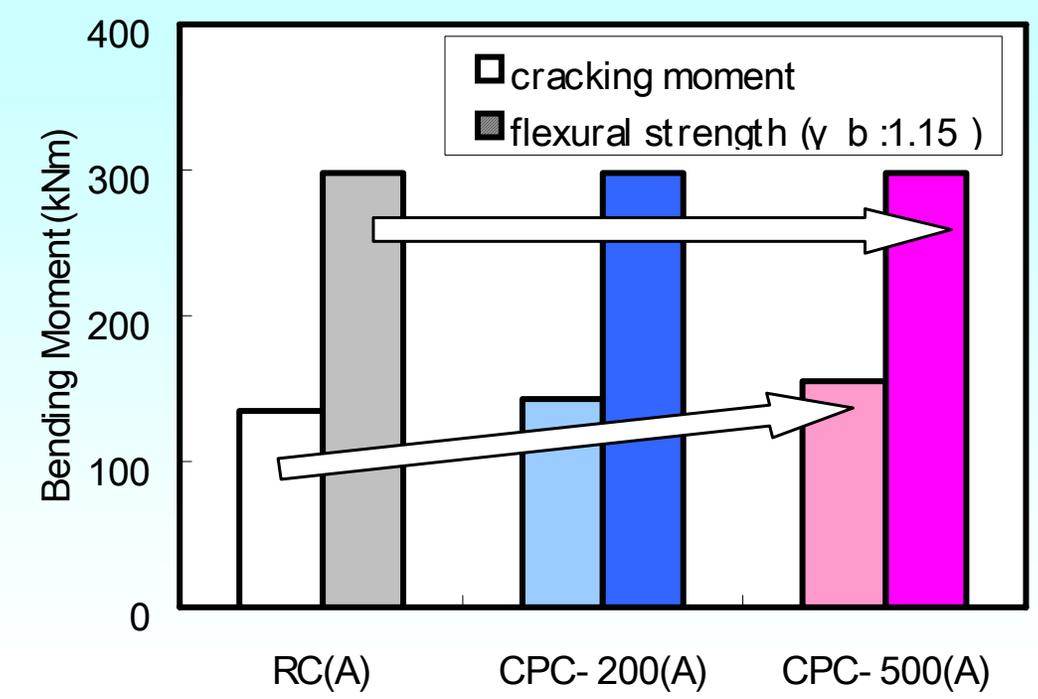
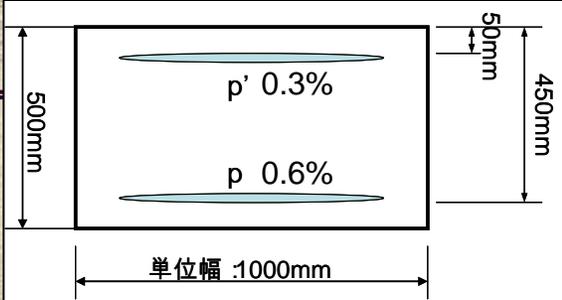
Reinforcement (Steel Bars)



The origin of the stress-strain curves of expansive concrete is moved according to chemical pre-stress and chemical pre-strain

Flexural Strength of CPC member

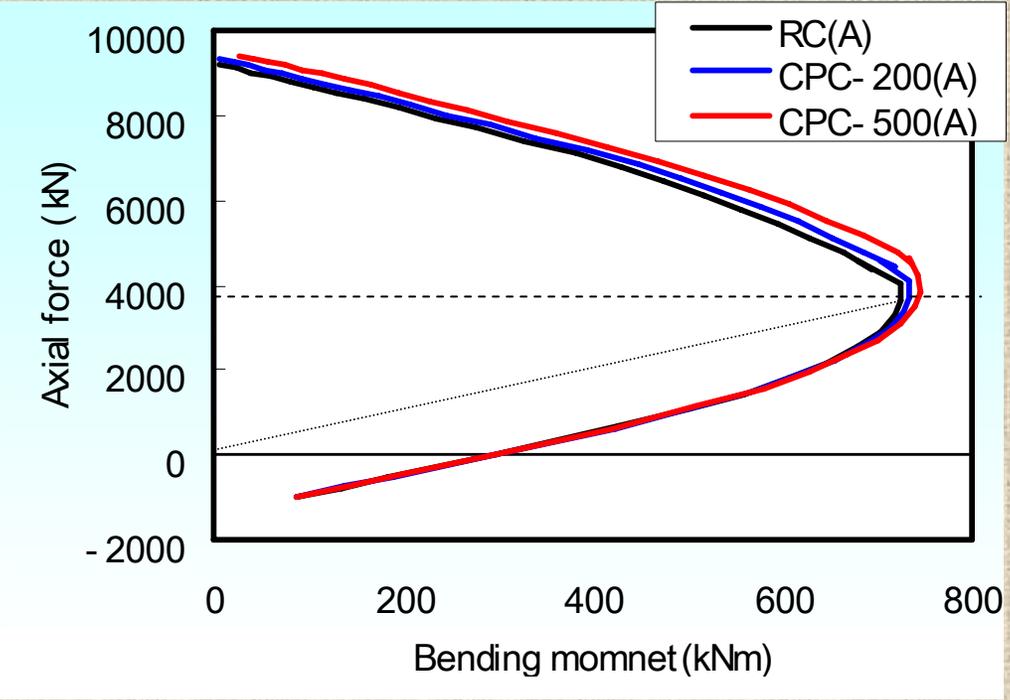
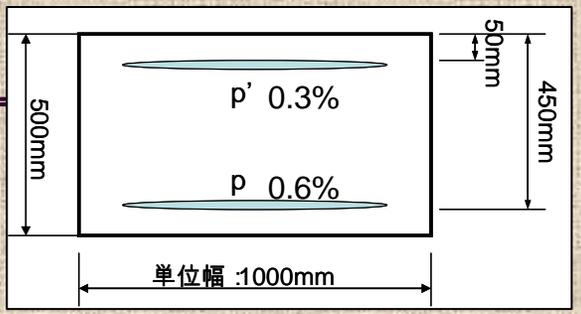
| | |
|---------|---|
| RC | Plain concrete (without expansive additive) |
| CPC-200 | Expansive concrete (Expansion; 200×10^{-6}) |
| CPC-500 | Expansive concrete (Expansion; 500×10^{-6}) |



a) The cracking moment increased by introducing the chemical pre-stress.
 b) Ultimate flexural strength of expansive concrete is almost same as plain concrete one. The reason of yield strength of reinforcement is same with of both expansive concrete and plain one.

Interactive curves of CPC member

- RC Plain concrete (without Expansive additive)
- CPC-200 Expansive concrete (Expansion; 200×10^{-6})
- CPC-500 Expansive concrete (Expansion; 500×10^{-6})



Likewise,
Ultimate strength of expansive concrete equals to plain concrete one.

4. Controlling crack and crack width by expansive concrete

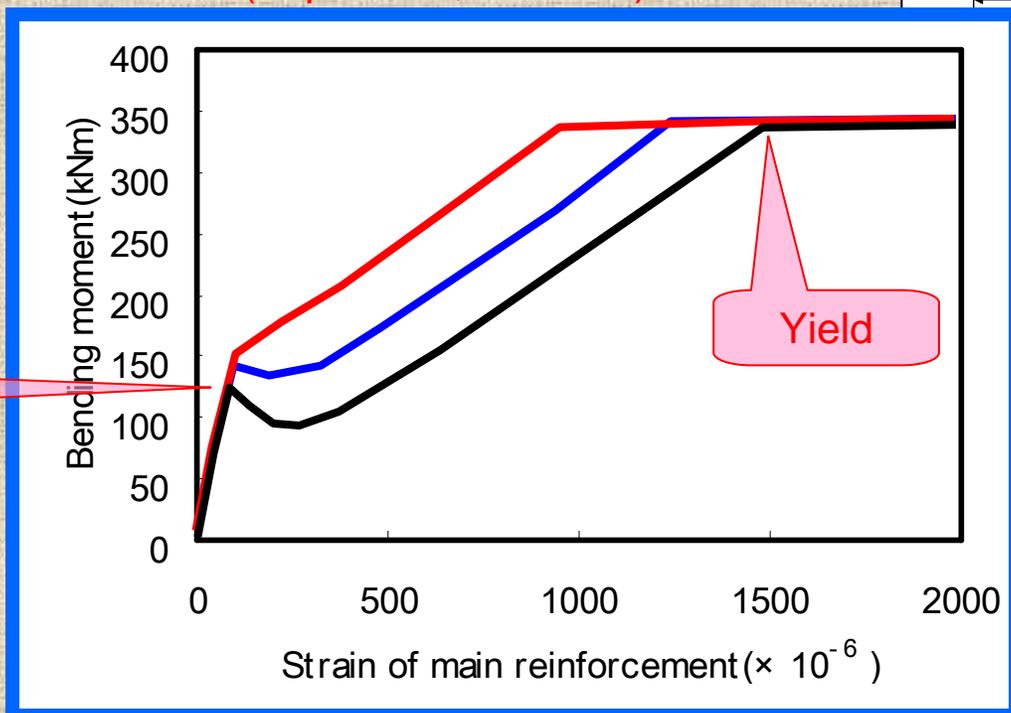
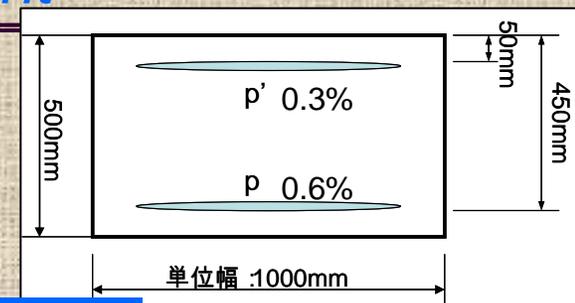
Crack width relates to the strain of main reinforcement and the distance between each cracks.

| Crack width w (mm) | Japan Society of Civil |
|---|------------------------------|
| $w = \underbrace{1.1 \cdot k_1 \cdot k_2 \cdot k_3 \{4c + 0.7(c_s - \phi)\}}_{\text{Sectional Factors}} \underbrace{\left[\frac{\sigma_{se}}{E_s} + \varepsilon'_{csd} \right]}_{\text{Strain of tensile steel bars}}$ | |
| Sectional Factors (Distance between each cracks) | Strain of tensile steel bars |

The strain of the main reinforcement can evaluate the crack width of the concrete

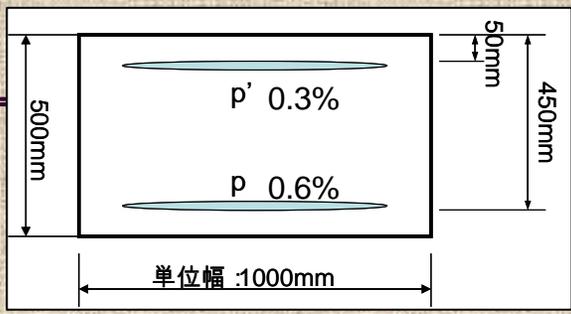
Bending moment and Strain of reinforcement

- Case1 Plain concrete
- Case2 Expansive concrete (Expansion; 200×10^{-6})
- Case3 Expansive concrete (Expansion; 500×10^{-6})

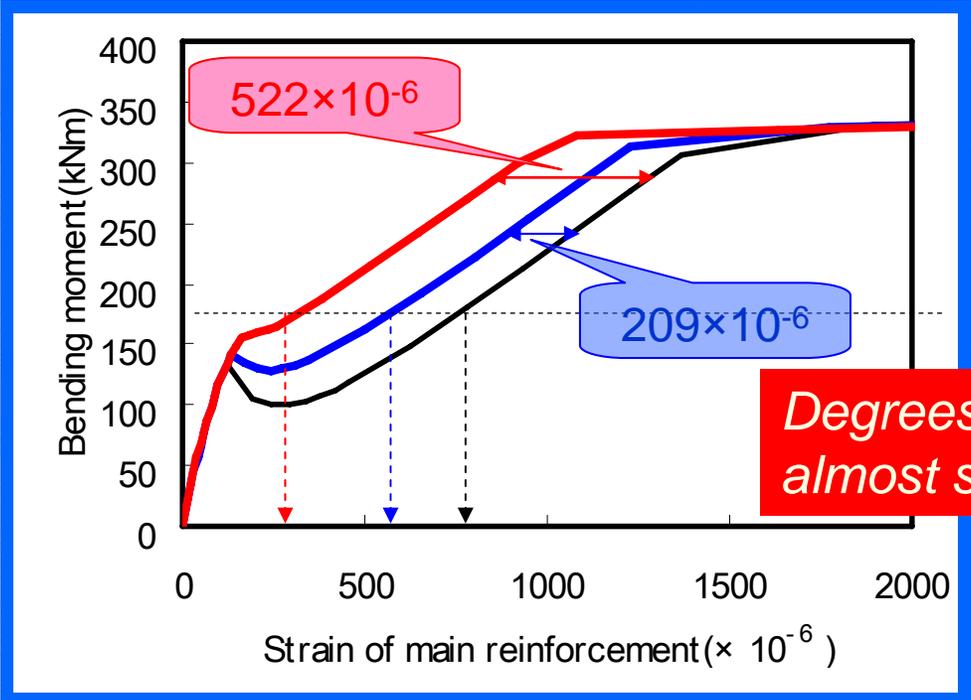


The cracking moment, increased with the introduction of the chemical pre-stress.

Effect of Expansive concrete



- Case1 Plain concrete
- Case2 Expansive concrete (Expansion; 200×10^{-6})
- Case3 Expansive concrete (Expansion; 500×10^{-6})

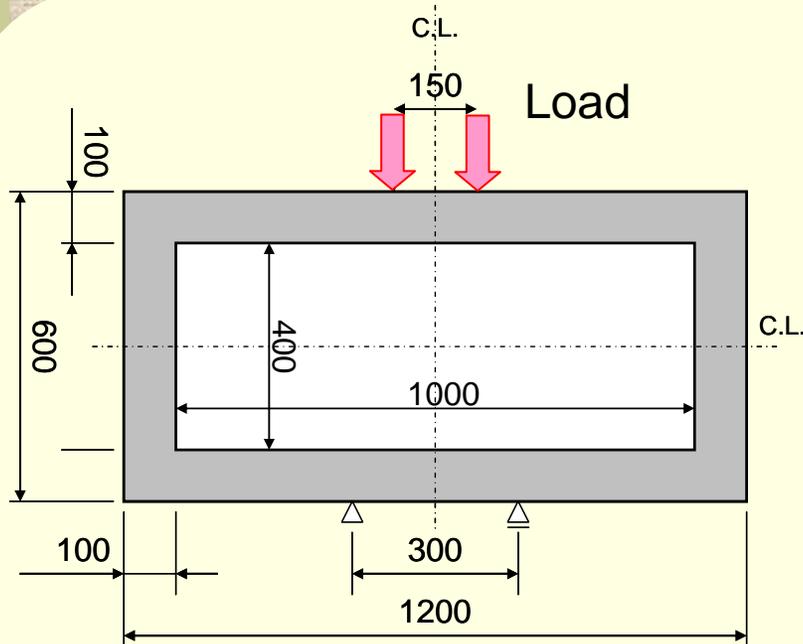


Degrees of decreasing is almost same as pre-strain.

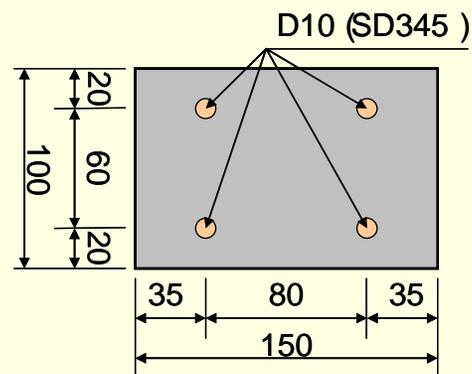
For the same bending moment, the strain of reinforcement of the expansive concrete is small. The reason of chemical pre-strain is introduced into the reinforcement.

Experiment

Loading test of Box culvert



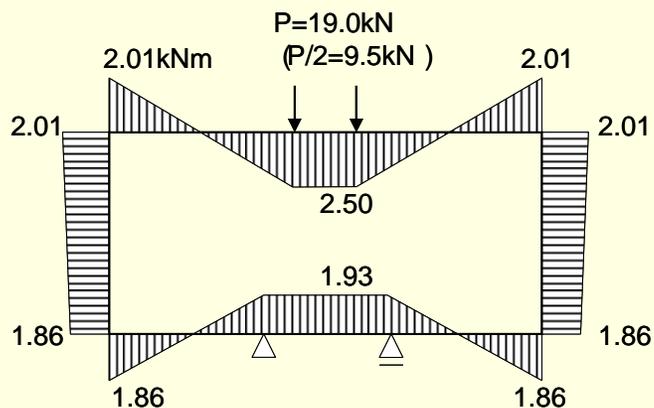
Method of loading test



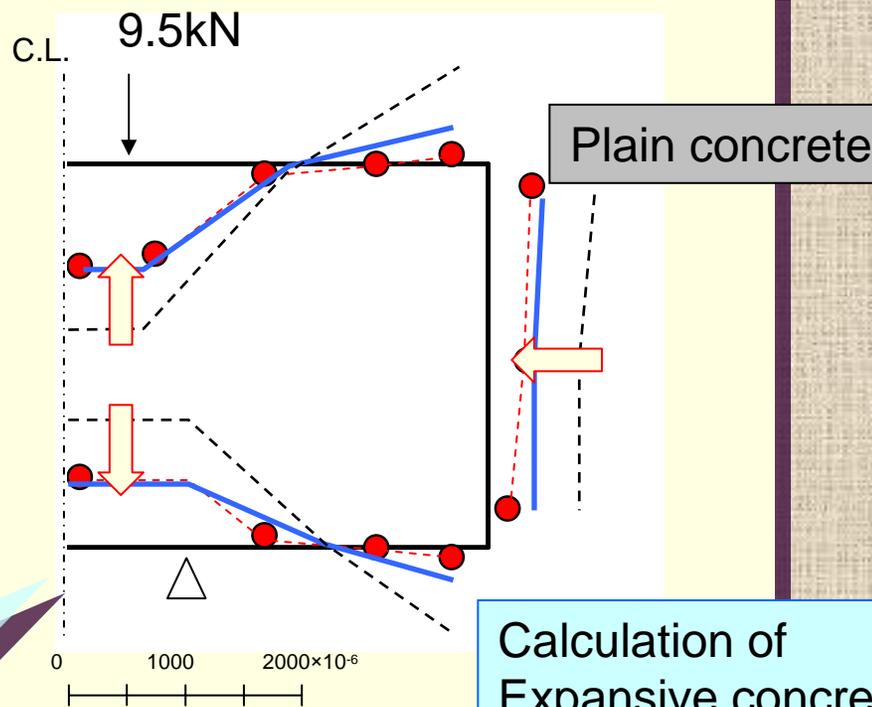
Cross section

Effect of chemical pre-strain

● ; Measured value of strain of reinforcement



Bending moment diagram

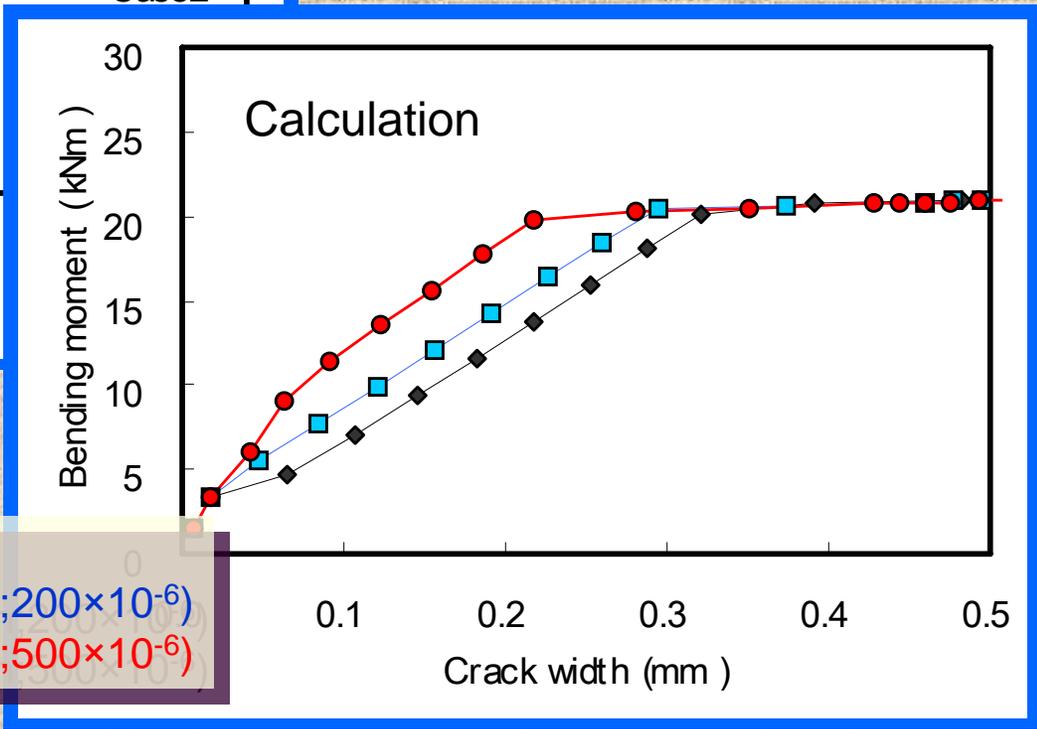
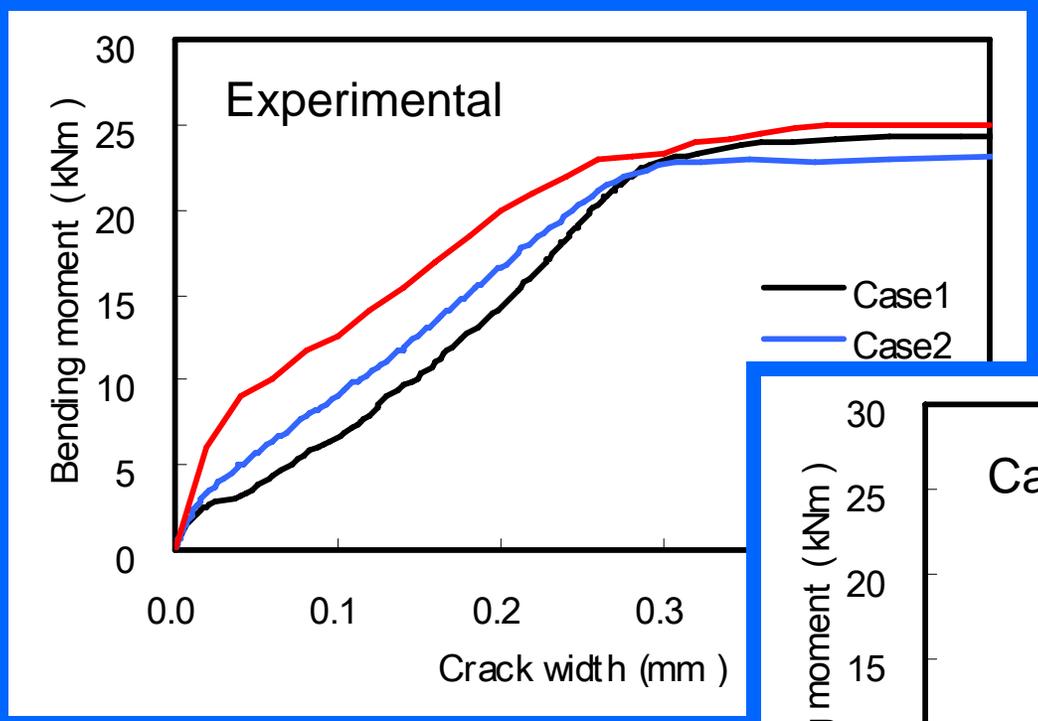


Calculation of Expansive concrete

Loading test results; Strain of reinforcement

For the same Load, Strain of reinforcement decreases by chemical pre-strain using expansive additive.

Crack width



- Case1 Plain concrete
- Case2 Expansive concrete (Expansion; 200×10^{-6})
- Case3 Expansive concrete (Expansion; 500×10^{-6})

Conclusion

- (1) The concept of work done for expansive concrete can estimate both chemical pre-stress and chemical pre-strain.
- (2) The Fiber model with The concept of work done can evaluate mechanical behaviors of the expansive concrete members.
- (3) Crack width of reinforced concrete decreases using an expansive additive. Degree of decreasing crack width is corresponds to with degree of chemical pre-strain.

The control of the crack width using expansive concrete can greatly extend the life of concrete structures.

Thank you very much for your attention.

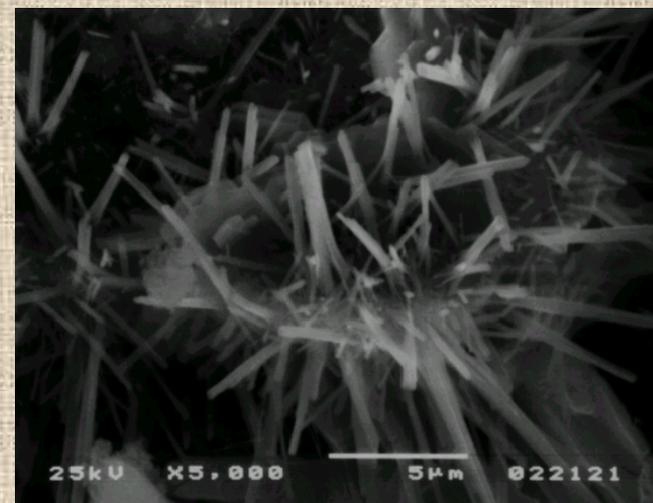
Please E-mail your question and comment to the following.

kentaro-suhara@denka.co.jp

Expansive additive 'CSA'

Expansive additive 'CSA' is produced by crushing a sintered compound mainly consisting of limestone, gypsum, and bauxite (calcium oxide, calcium sulfate and aluminum oxide) in adequate amounts. The chemical composition of sintered CSA clinker mainly consists of hauyne, free lime and free gypsum.

Hydration of these minerals forms ettringite ($3\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 3\text{CaSO}_4\cdot 32\text{H}_2\text{O}$), a very small crystal with dimensions of several microns. In the cement paste hardening process, this colloid-like crystal becomes burr-like within minute gel voids. It thus reduces hardening shrinkage and dry shrinkage of the gel, and furthermore it acts to expand the gel. Therefore, the presence of ettringite increases the density of the concrete matrix, reduces dry shrinkage, and induces compressive stress into a concrete structure under a restrained condition. Through the above mechanism, CSA reduces dry shrinkage cracking in concrete and increases the water-tightness of concrete structures.



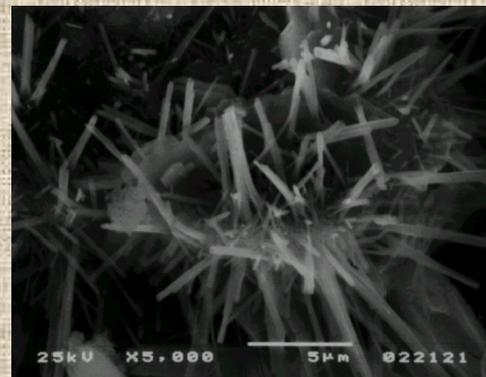
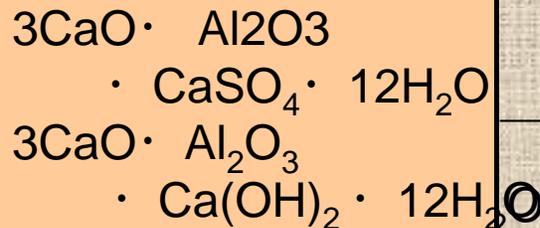
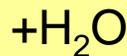
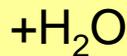
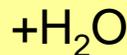
Scanning electron microscopy image of ettringite



What is DENKA CSA? (Properties of CSA)

Hydration System

CSA's ingredients



Expansive substance
"Ettringite"

膨張コンクリートによるひび割れ幅の制御

<<RC部材のひび割れ，ひび割れ幅の制御>>

(1) コンクリート強度の増加

(2) 鉄筋量の増加

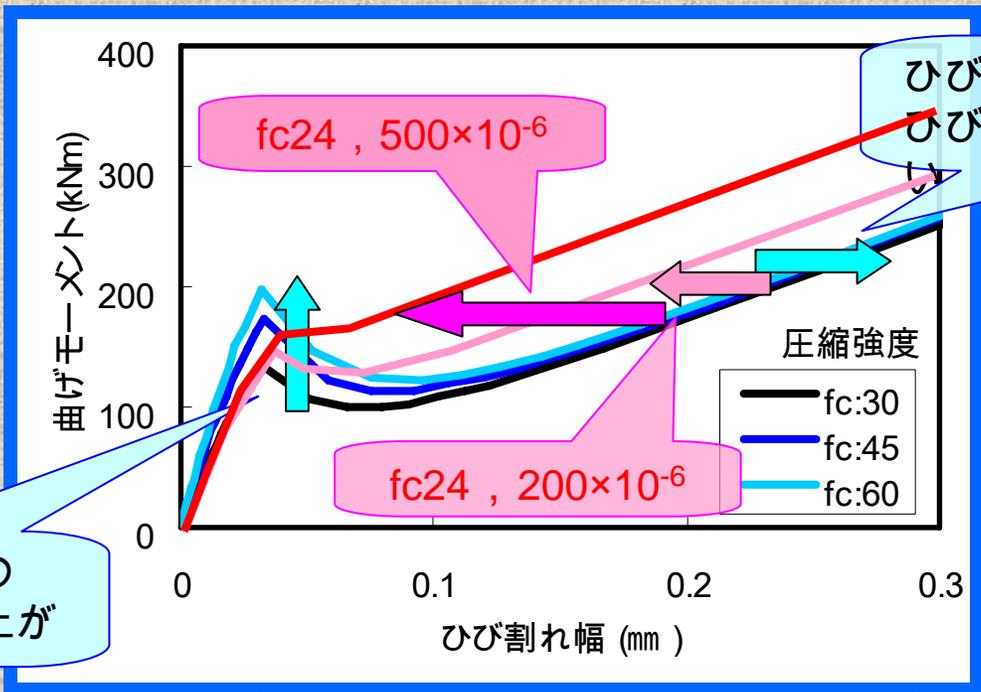
(3) 鉄筋の配置間隔の制御

(4) 膨張コンクリート

膨張コンクリートによるひび割れ幅の制御

(1) コンクリート強度の増加

同一断面で，コンクリートの圧縮強度 (30 , 45 , 60N/mm²) を水準として算定



ひび割れ発生時の曲げモーメントは上がる

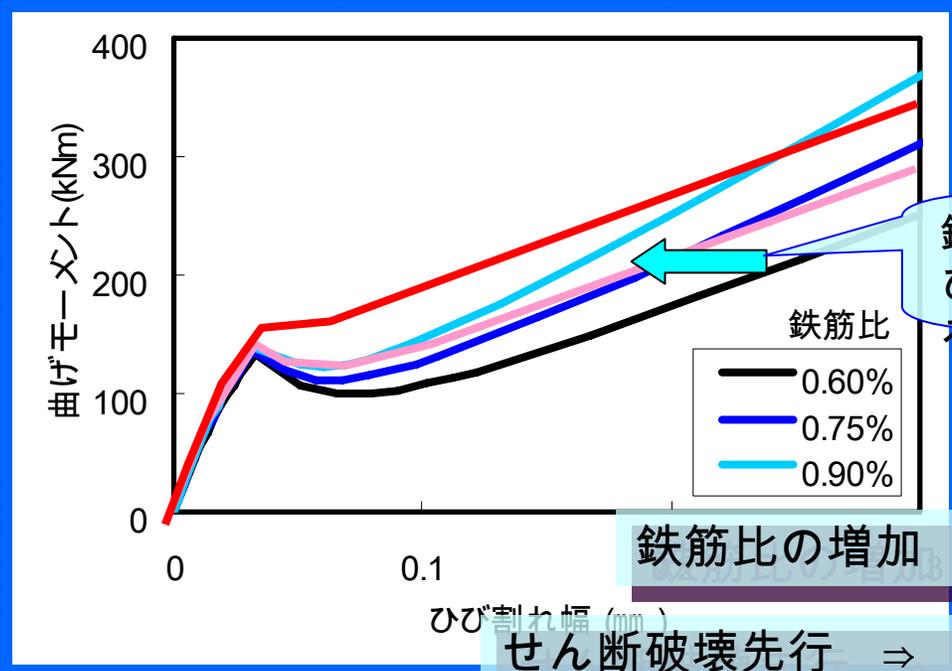
ひび割れ発生後のひび割れ幅は，制御できない

- ・ 圧縮強度の増加は，単にひび割れ発生時の曲げモーメントを増加させるだけ
- ・ 膨張コンクリートは，ひび割れ制御に，より有効にはたらく

膨張コンクリートによるひび割れ幅の制御

(2) 鉄筋量の増加

同一断面で，引張鉄筋の鉄筋量（0.6%，0.75%，0.9%）を水準として算定



鉄筋比に応じてひび割れ幅を制御できる



鉄筋比の増加 ⇒ 曲げ耐力の増加

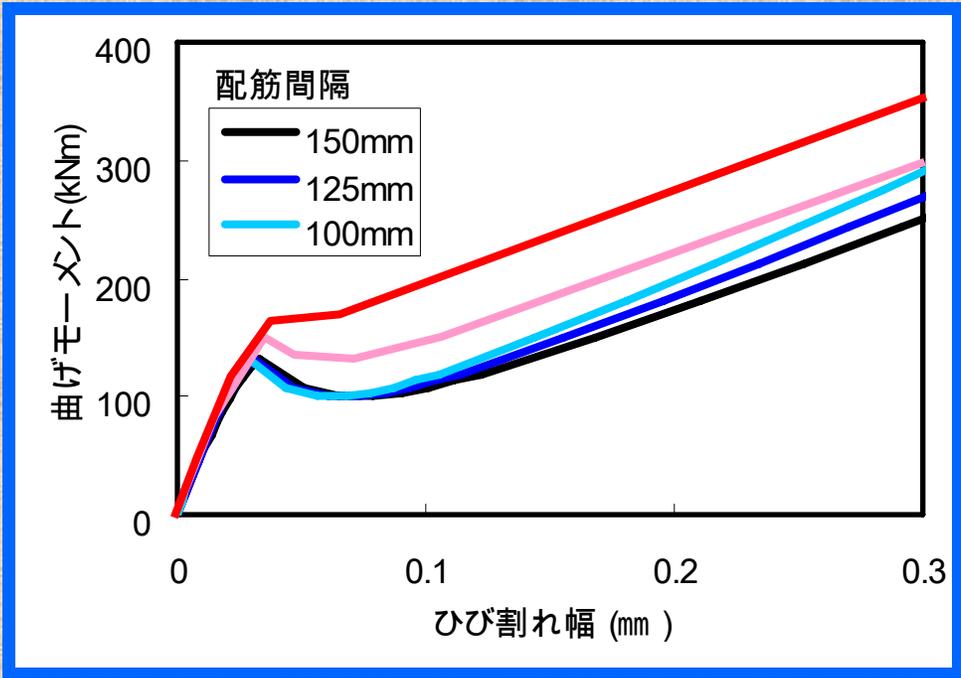
せん断破壊先行 ⇒ せん断補強筋の増加

・ 鉄筋比の増加は，ひび割れ幅を制御できるが，非経済的な断面設計となる

膨張コンクリートによるひび割れ幅の制御

(3) 鉄筋の配置間隔による制御

同一断面で，鉄筋の配置間隔 (150mm , 125mm , 100mm) を水準として算定



・ 配筋間隔によるひび割れ幅の影響は，小さい

膨張コンクリートによるひび割れ幅の制御

| 制御方法 | ひび割れ発生に対して | ひび割れ幅に対して |
|-------------|------------|-----------|
| コンクリート強度の増加 | ○ | × |
| 鉄筋量の増加 | × | ○ |
| 鉄筋の配置間隔の制御 | × | △ |
| 膨張コンクリート | ○ | ○ |

第7章 結論

<<粒度の及ぼす膨張への影響>>

(1) 膨張量は，膨張材の粒子の個数と表面積との積で整理できる．

(2) 膨張材の粒度を調整することで，
積極的にケミカルプレストレスを導入できることが確認された．



膨張材粒子の仕事は，一様であると考えられるが，構成する粒度により，仕事量を制御できる．

第7章 結論

<<C P C 部材の限界状態設計>>

(1) 仕事量一定則を適用することで，C P C 部材のC P を評価することができ

(2) 積層モデルによる断面解析を適用することで，
C P C 部材の断面耐力，断面応力度を適切に評価することが可能である．



膨張コンクリートのひび割れ幅の制御を
定量的に表すことが可能である．

膨張材によるケミカルプレストレインを考慮
した
限界状態設計法

ご清聴いただき、ありがとうございました。

設計法の違い

鉄筋コンクリート構造物の設計形態

許容応力度設計法

通常の使用状態で発生する**最大応力度と材料強度**との比較

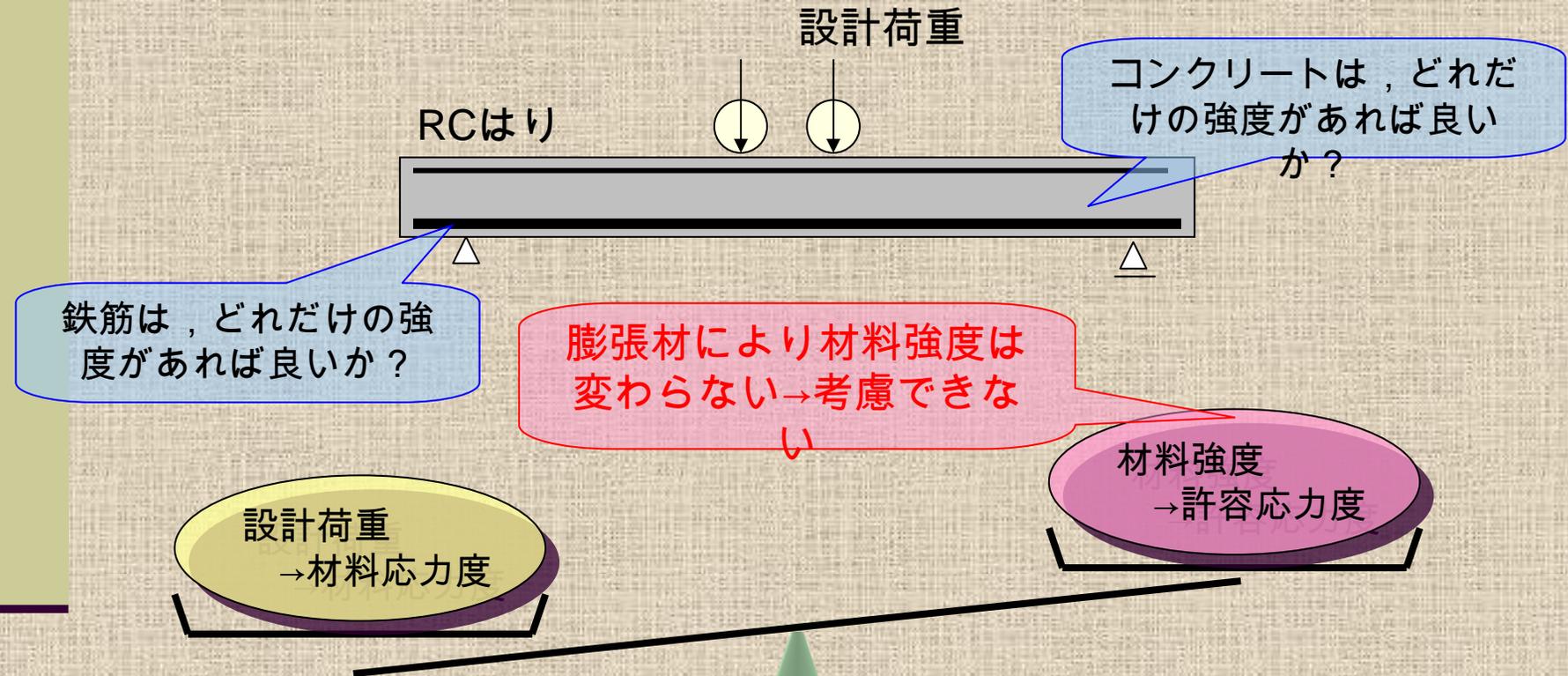
→ 簡便でわかりやすいことから，長期にわたり採用されてきた

限界状態設計法

各限界状態に対して，断面耐力等の**安全性を照査**する方法

→ 昭和61年のコンクリート標準示方書の改訂において採用

許容応力度設計法の例



通常の使用状態での最大荷重により生じる材料応力度が，許容応力度以下であることを確認する。

限界状態設計法の例



構造物がその状態に達すると、破壊 / 使用できないなどの各限界状態に対して、安全性の照査を行う。

戻る

限界状態設計法の流れ

設計荷重

断面耐力算定
(積層モデル)

+ 膨張ひずみ分布
ケミカルプレストレス
ケミカルプレストレス



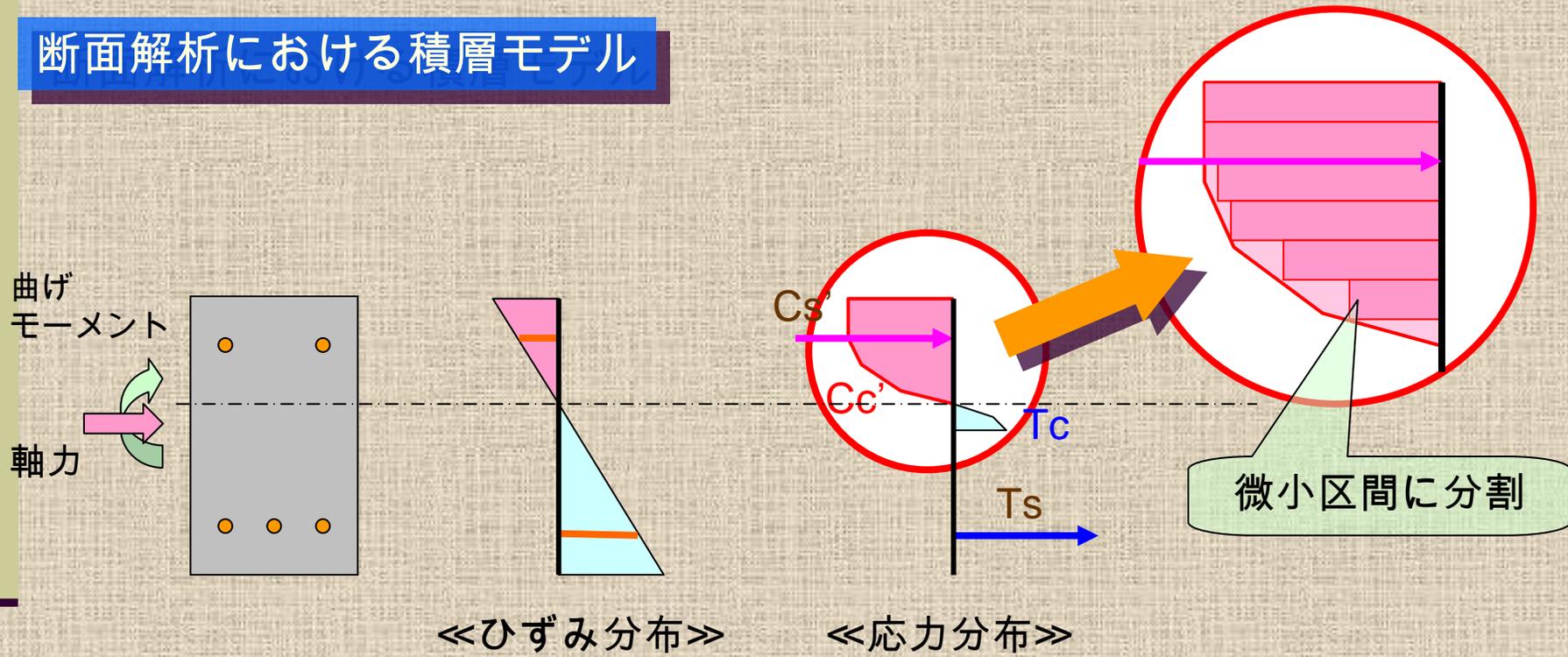
断面力算定
(骨組解析など)

照査
(耐力、ひび割れ幅
等)

積層モデル

Fiber Model

断面解析における積層モデル



終局耐力

CPC部材のせん断耐力

$$V_{yd} = V_{cd} + V_{sd}$$

せん断補強筋

$$V_{sd} = \left[A_w f_{wyd} (\sin \alpha_s + \cos \alpha_s) / S_s \right] z / \gamma_b$$

せん断補強筋で決まる

コンクリート

$$V_{cd} = \beta_d \beta_p \beta_n f_{vcd} b_w d / \gamma_b$$

$$f_{vcd} = 0.20 \sqrt[3]{f'_{cd}}$$

$$\beta_d = \sqrt[4]{1/d}$$

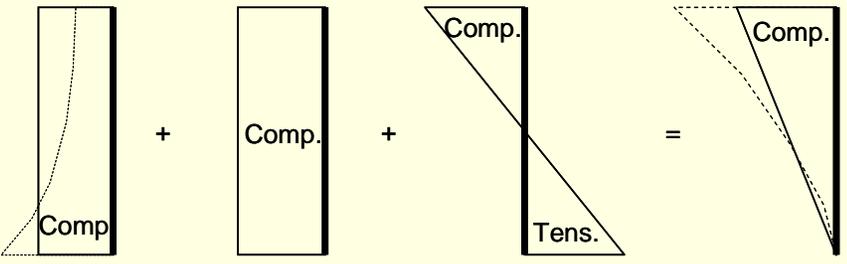
$$\beta_p = \sqrt[3]{100 P_v} = \sqrt[3]{100 \frac{A_s}{b_w d}}$$

部材の断面形状

$$\beta_n = 1 + M_0 / M_d \quad (N'_d \geq 0)$$

$$= 1 + 2 M_0 / M_d \quad (N'_d < 0)$$

デコンプレッションモーメント M_0



CP

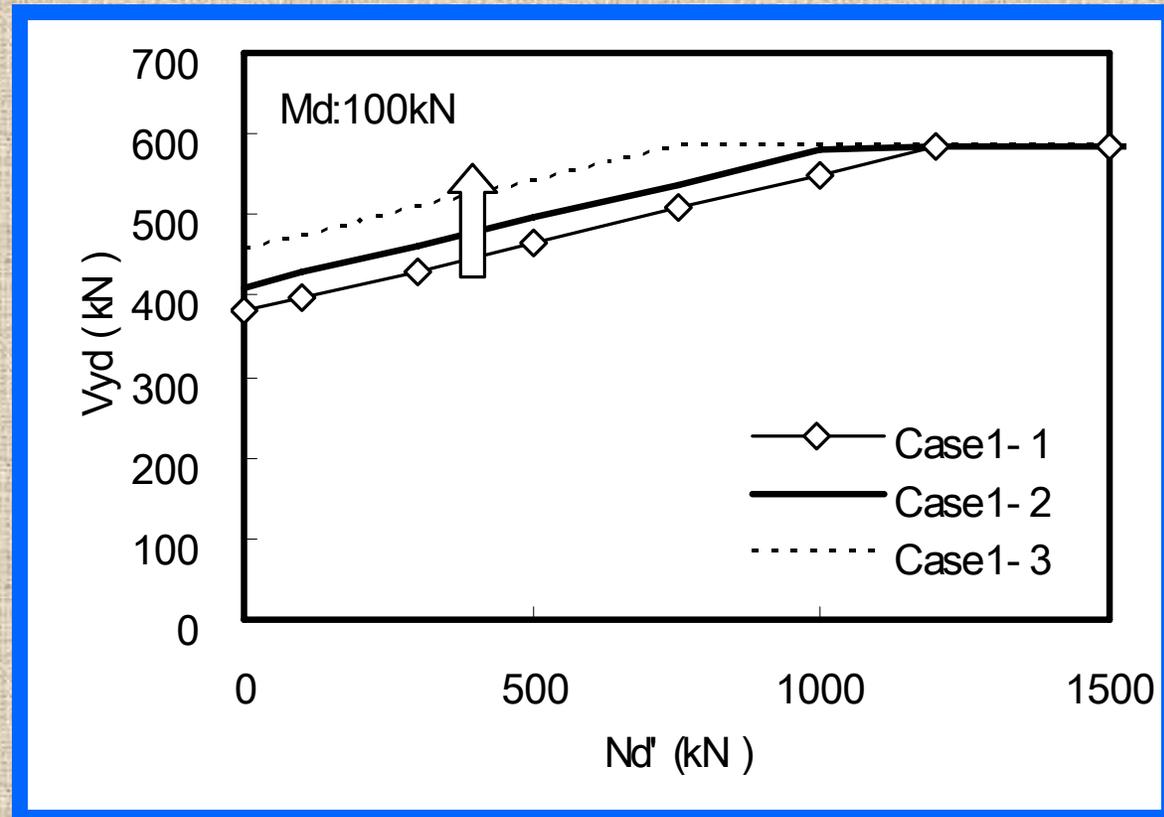
Nd

M_0

合成後

ケミカルプレストレスにより，デコンプレッションモーメントが増加し，これに応じて，部材のせん断耐力が向上する。

CPC部材のせん断耐力



通常は、曲げ破壊が先行するように設計するため、せん断耐力の向上は、設計上、クリティカルになることはない。

許容ひび割れ幅

ひび割れに対する検討

<<鉄筋コンクリート構造物のひび割れ>>

鉄筋コンクリートは、ひび割れを許容する材料

(1) 無害なひび割れ

(2) 有害なひび割れ

→ 鋼材の機能を低下 (腐食) させるひび割れ

使用性の照査・・・ひび割れに対する検討が重要

許容ひび割れ幅

鋼材の機能を維持するために、
目的に応じて、許容ひび割れ幅が定められている。

鋼材の腐食に対する許容ひび割れ幅 (mm)

| 鋼材の種類 | 鋼材の腐食に対する環境条件 | | |
|-----------|---------------|--------|------------|
| | 一般の環境 | 腐食性環境 | 特に厳しい腐食性環境 |
| 異形鉄筋・普通丸鋼 | 0.005c | 0.004c | 0.0035c |
| P C 鋼材 | 0.004c | - | - |

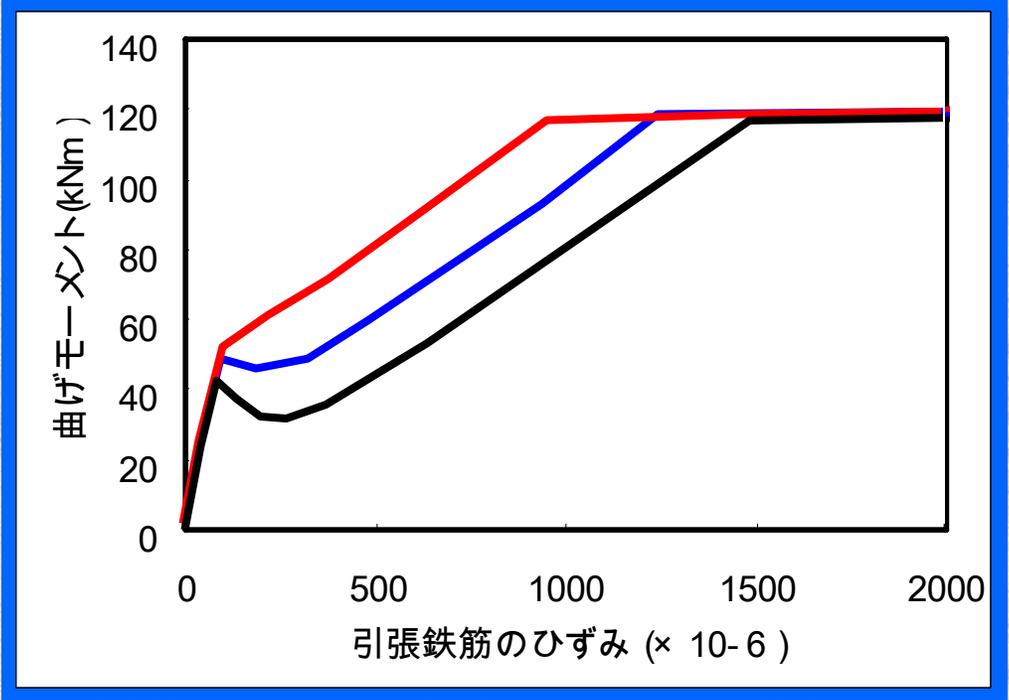
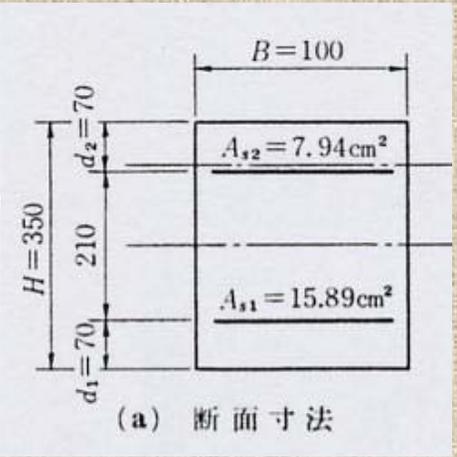
c : かぶり (mm)

<<土木学会 コンクリート標準示方書より>>

ケミカルプレストレイン

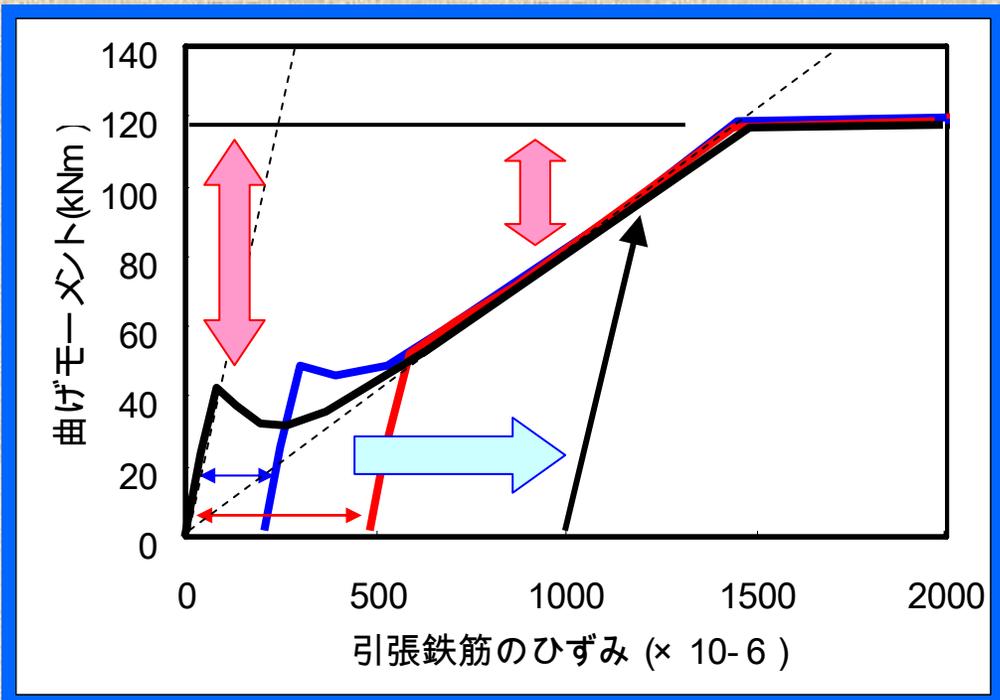
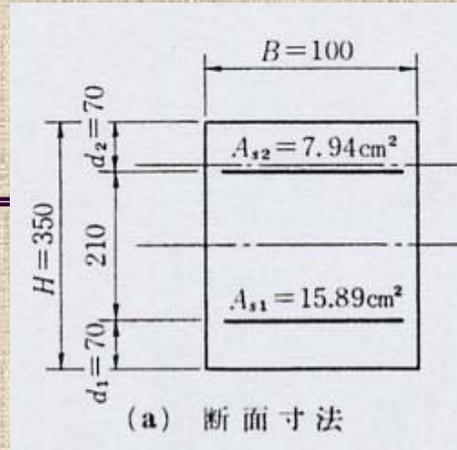
引張鉄筋のひずみと曲げモーメント

- Case1 普通コンクリート
- Case2 膨張コンクリート : 200×10^{-6}
- Case3 膨張コンクリート : 500×10^{-6}



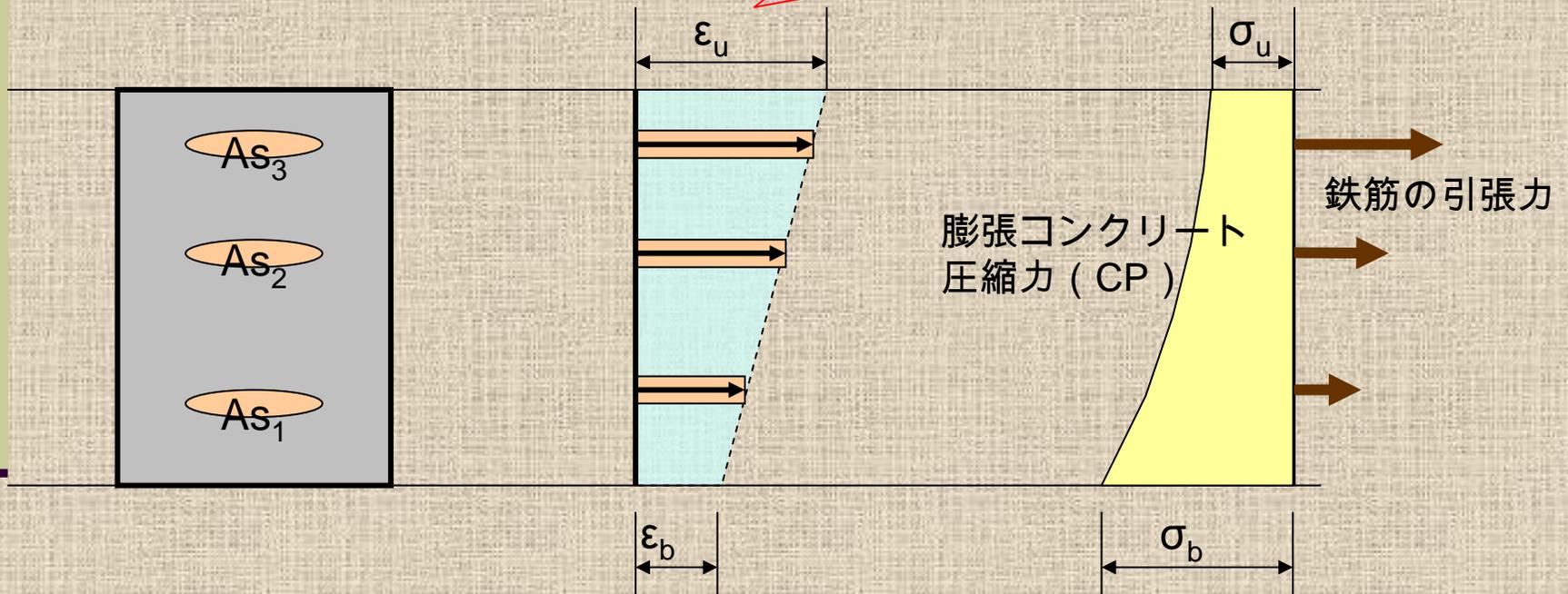
引張鉄筋のひずみと曲げモーメント

- Case1 普通コンクリート
- Case2 膨張コンクリート : 200×10^{-6}
- Case3 膨張コンクリート : 500×10^{-6}



積極的にCPを入れる場合，これに見合う鉄筋が必要
(鉄筋量の増加，降伏点の大きい鉄筋を採用)

拘束の弱い端部の膨張ひずみ
例えば， 800×10^{-6} 以下に制御



<<長さ変化率>>

<<応力分布>>

基準となる膨張ひずみ
(JIS A 6202 A法・ B法など)

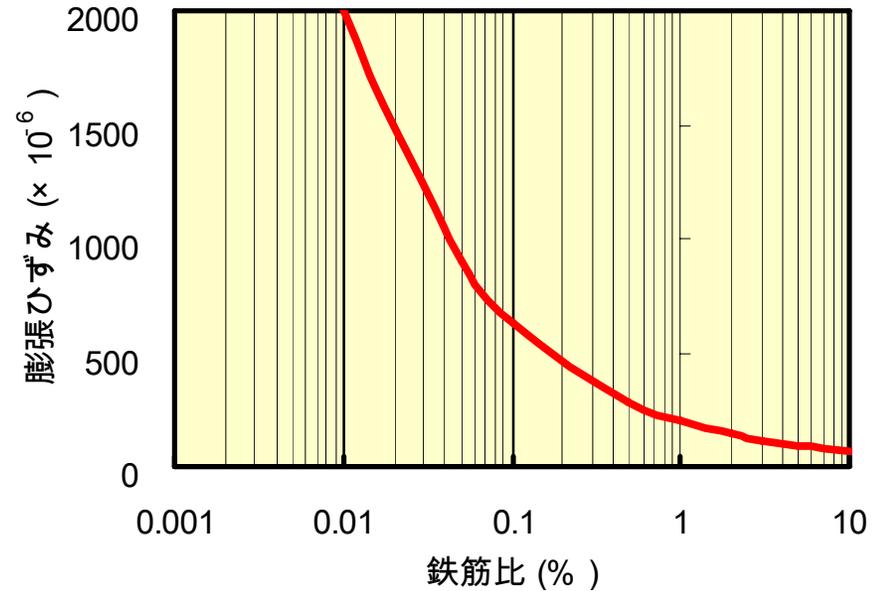
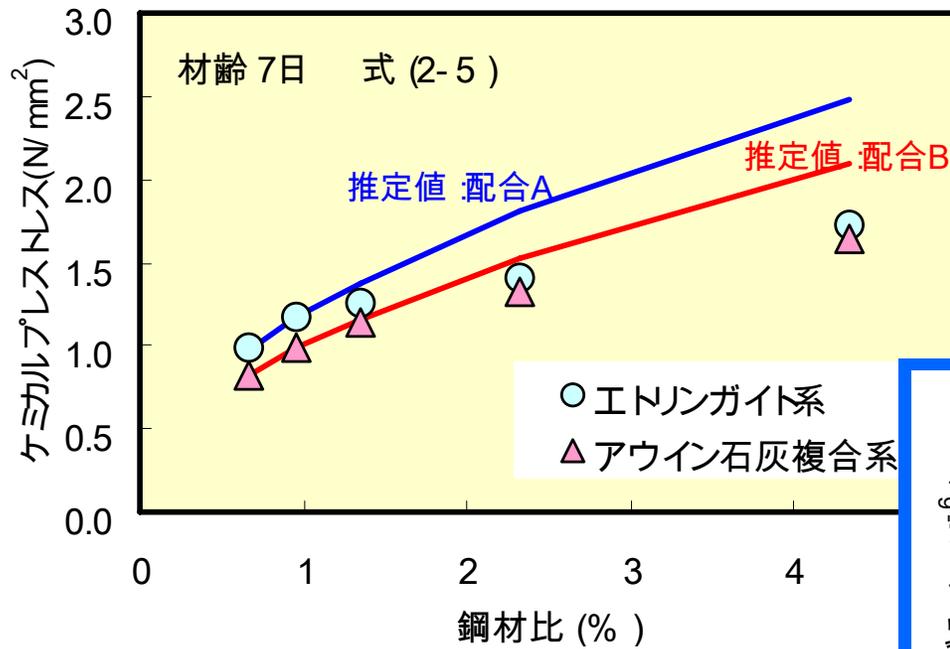


収縮補償を目的とした場所打ち用途
 $150 \sim 250 \times 10^{-6}$

ケミカルプレストレス導入用コンクリート (工場)
 $200 \sim 1000 \times 10^{-6}$

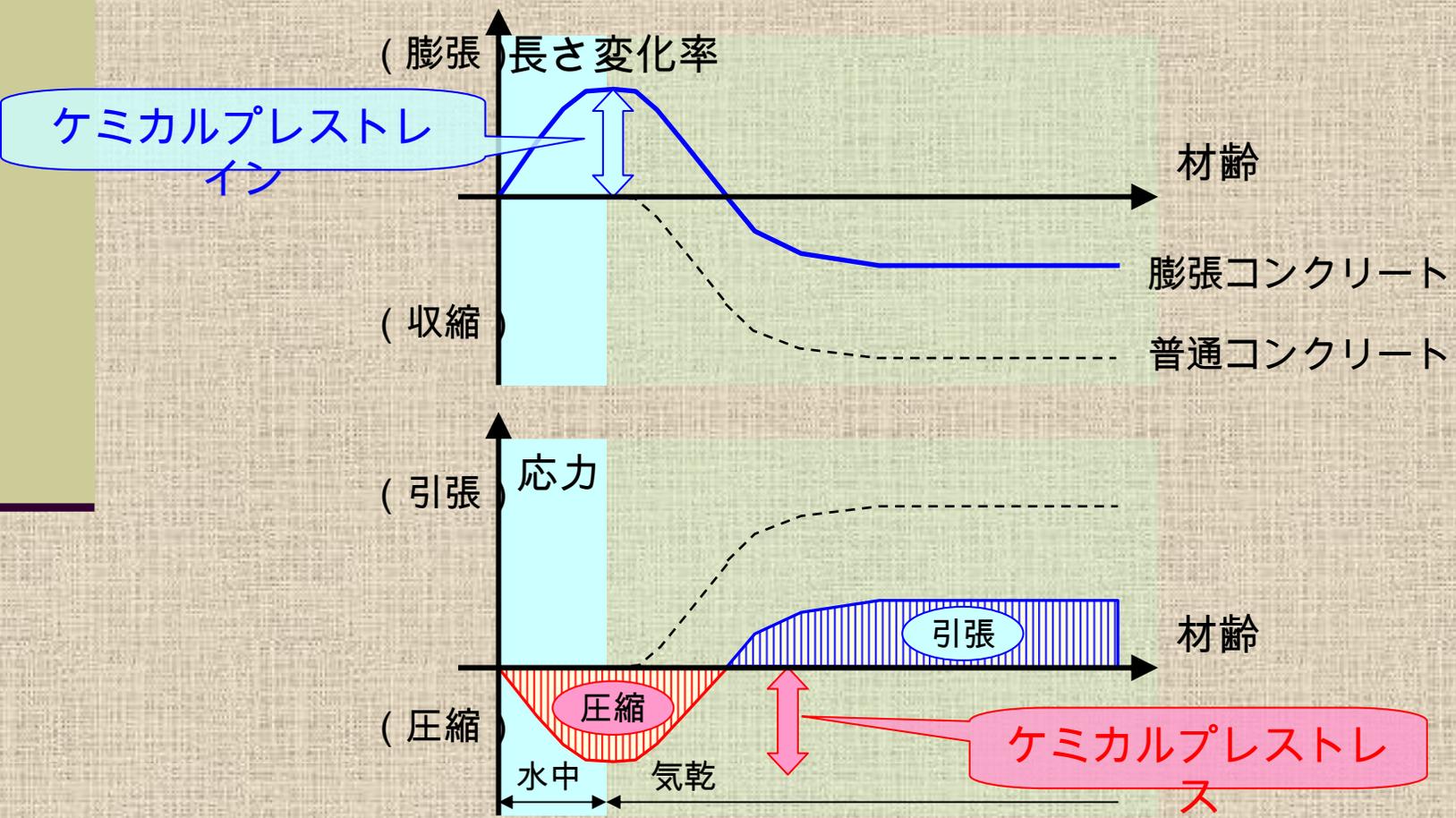
→ 実際は, 700×10^{-6} 程度を上限

仕事量一定則の適用範囲



膨張材は、何故ひび割れを抑制するのか？

膨張コンクリートは、水和の過程で、体積変化（膨張）する



膨張コンクリートの伸び能力

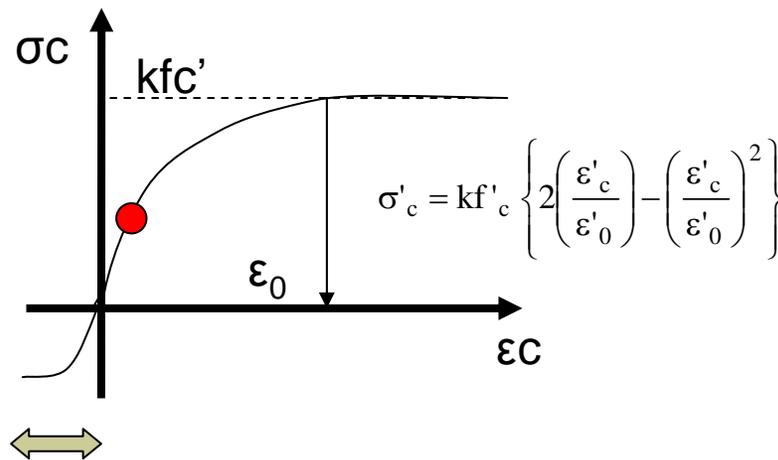
参考 5 膨張コンクリートは，伸び能力が大きい

→ ひび割れ発生時の引張ひずみが大きい

普通コンクリート： $50 \sim 150 \times 10^{-6}$

膨張コンクリート： $100 \sim 300 \times 10^{-6}$

コンクリートの応力ひずみ曲線



CPC部材の実験結果例

提案したモデルの検証

Step.1 CPC部材レベルでの検証

CPCはりの曲げ載荷実験

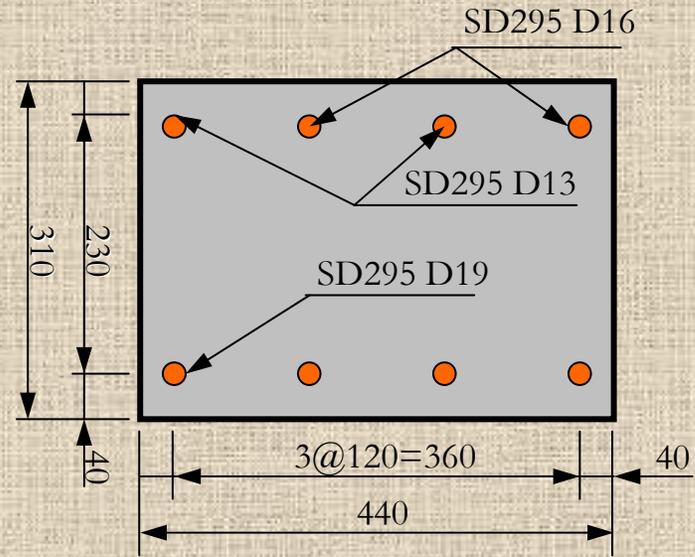
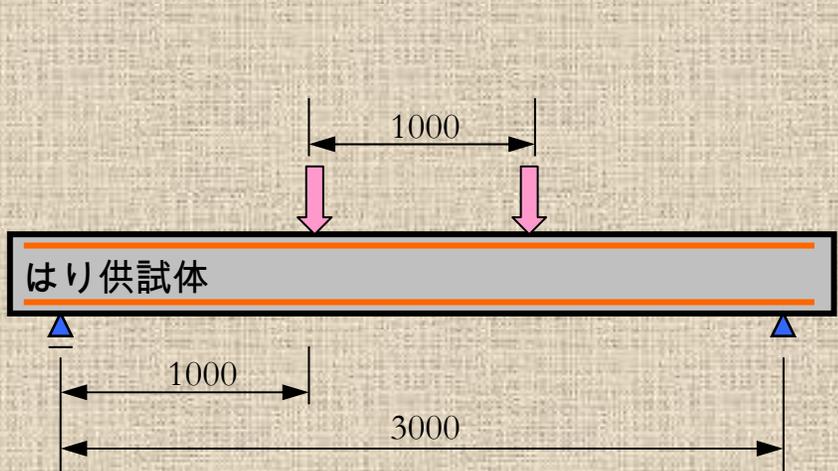
→ 曲げ性状，せん断性状，ひび割れ性状

Step.2 構造物レベルでの検証

ボックスカルバートの載荷実験

→ 引張鉄筋のケミカルプレストレインの効果を検証

Step. 1 部材レベルでの検証



| 配合 | W/C (%) | s/a (%) | Air (%) | 単位量 (kg/m ³) | | | | | |
|------|------------|------------|------------|--------------------------|-----|----|-----|-----|------|
| | | | | W | C | EX | S | G | Add |
| 普通コン | 47 | 49 | 2.0 | 168 | 357 | 0 | 904 | 955 | 1.97 |
| 膨張コン | 45 | 48 | 2.0 | 168 | 313 | 60 | 879 | 967 | 2.05 |

Step. 1 断面耐力

V/M > 1 : 曲げ破壊
 V/M < 1 : せん断破壊

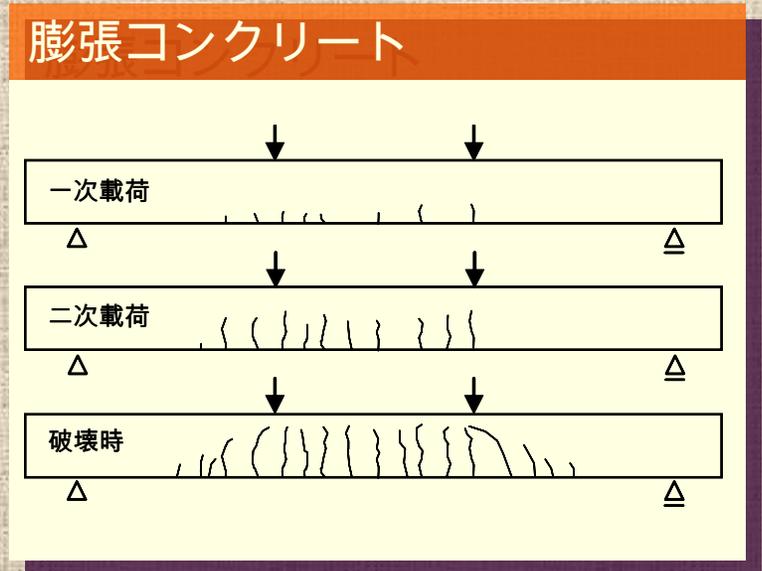
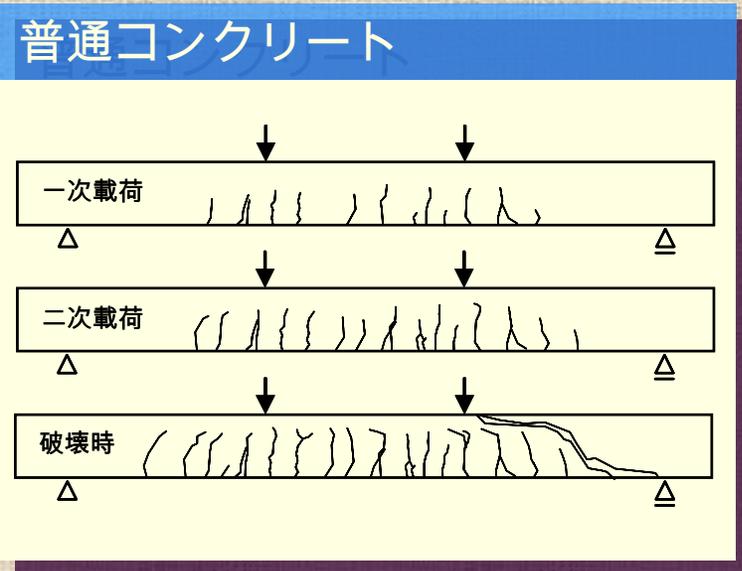
| | 破壊荷重 (kN) | 破壊形式 | 解析値 | | |
|------|-----------|-------|-----------------|------------------|------|
| | | | 曲げ耐力時の荷重 M (kN) | せん断耐力時の荷重 V (kN) | M/V |
| 普通コン | 268.6 | せん断*1 | 213.2 | 226.2 | 1.06 |
| | 297.5 | せん断*1 | | | |
| | 293.9 | 曲げ引張 | | | |
| 膨張コン | 303.9 | 曲げ引張 | 216.2 | 269.3 | 1.25 |
| | 293.6 | 曲げ引張 | | | |
| | 309.3 | 曲げ引張 | | | |

普通コンの2体は、せん断破壊

曲げ耐力は、鉄筋の降伏に支配されるため、膨張材の影響はない

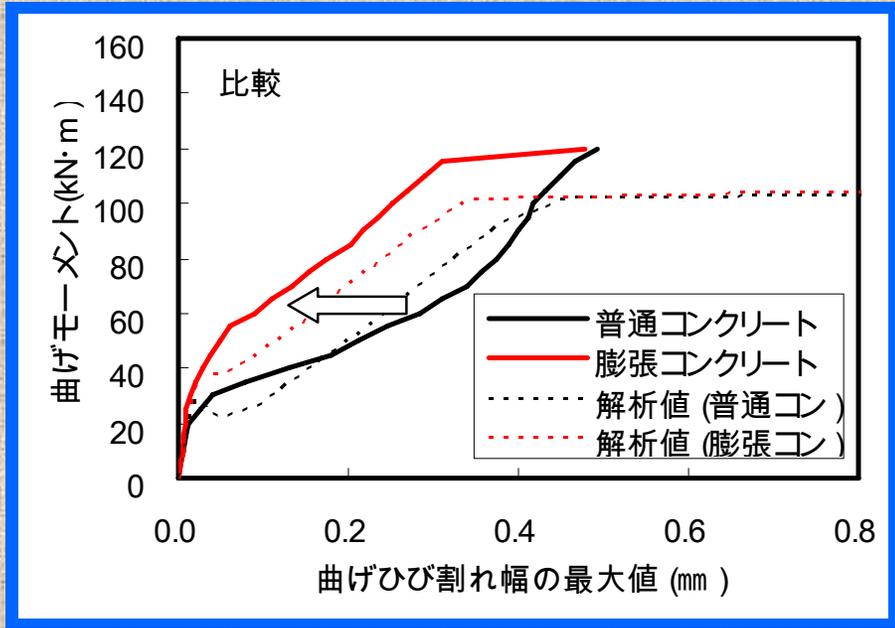
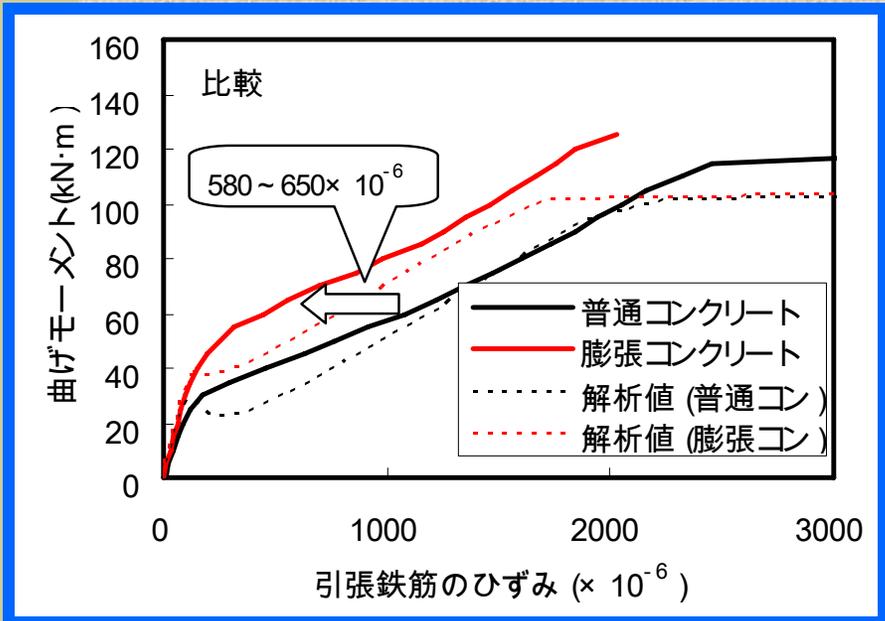
ケミカルプレストレスにより、せん断耐力が向上したことを示唆している

Step. 1 ひび割れ性状



膨張コンクリートは，同一の荷重において，ひび割れ本数も少なく，一様に分散している。

Step. 1 引張鉄筋のひずみ，ひび割れ幅



力の釣合い例

