フィレンデル型橋梁の解法

正 員 内 田 一 郎*

SOLUTION OF THE VIERENDEEL TYPE BRIDGES

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Ichiro Uchida, C.E. Member.

Synopsis The author solves the load and temperature stresses of spandrel braced Vierendeel type bridges by slope deflection method. The simultaneous equations from which the stresses are worked out can be mechanically tabulated, and these equations can be applied to all Vierendeel type bridges such as arch and truss bridges of Vierendeel type.

要旨 スパンドレルブレース型のフィレンデル橋梁の荷重及び温度応力を撓角法を用いて解いたもので、荷重応力に関しては部材の伸縮を考慮している。応力を求めるための連立方程式は表示して機械的な作表を可能にし、又アーチ橋、トラス橋等あらゆる型のフィレンデル橋梁に対してこの連立方程式が適用出来る事を示した。

1. 序 言

図-1 のような上下弦材とも曲つている一般的なフィレンデル型固定アーチ橋を考える。格間数は説明の便宜のため6個とする。部材の伸縮が、端モーメント M_{ab} を求める次の (I) 式に及ぼす影響は極めて小さいので、この (I) 式を基本式として使用する。

図-1

で、この (I) 式を基本式として使用する。

$$M_{ab} = K_{ab}(2\varphi_a + \varphi_b + \mu_{ab}) \dots (I)$$

2. 格間4辺形の幾何学的釣合

4 辺形 $(r-1)r(r+2)(r+1)$ が変形後 $(r-1)'r'(r+2)'(r+1)'$ に移つたとする (図-2)。

l, l' : それぞれ変形前後における部材の長さ

Δl : 変形前後における部材の長さの差(伸+, 縮-)

θ, θ' : それぞれ変形前後における部材の水平となす角度

図-2

ψ : 部材回転角

N : 部材の軸力

E : 材料の弾性係数

ε : 材料の膨脹係数

t : 部材の温度変化量

添字 $rl, ru, rv, (r+2)v$ はそれぞれ部材 $(r-1)(r+1), r(r+2), (r-1)r, (r+1)(r+2)$ を意味する。変形前後において4 辺形は何れも閉じている故

$$\Sigma l \cos \theta = 0, \quad \Sigma l \sin \theta = 0$$

$$\Sigma l' \cos \theta' = 0, \quad \Sigma l' \sin \theta' = 0$$

然るに $l' = l + \Delta l$, $\theta' = \theta - \psi$

$$\therefore \Sigma l' \cos \theta' = \Sigma l (\cos \theta \cos \psi + l \sin \theta \sin \psi + \Delta l \cos \theta \cos \psi + \Delta l \sin \theta \sin \psi) = 0$$

$$\Sigma l' \sin \theta' = \Sigma l (\sin \theta \cos \psi - l \cos \theta \sin \psi + \Delta l \sin \theta \cos \psi - \Delta l \cos \theta \sin \psi) = 0$$

ψ は極めて小さいから $\sin \psi = \psi$, $\cos \psi = 1$ とおき、更に $\Sigma \Delta l \psi \sin \theta$ 及び $\Sigma \Delta l \psi \cos \theta$ は2次の微小量であるから

* 九州大学助教授、工学部土木教室

無視すれば $\Sigma l \psi \sin \theta + \Sigma \Delta l \cos \theta = 0$

$$-\Sigma l \psi \cos \theta + \Sigma \Delta l \sin \theta = 0$$

この両辺に $-6E$ を乗じ、 $\Delta l = \frac{N}{EA} l + \epsilon l$ を入れれば

$$\Sigma l \mu \sin \theta - 6 \Sigma \frac{N}{A} l \cos \theta - 6 \Sigma E \epsilon l \cos \theta = 0$$

$$\Sigma l \mu \cos \theta + 6 \Sigma \frac{N}{A} l \sin \theta + 6 \Sigma E \epsilon l \sin \theta = 0$$

今の場合、各部材の材料、温度変化量ともに同一と考える。部材毎に材料、温度変化量異なる場合についても同様に解く事が出来る。

E, ϵ 及び t は一定、 $\Sigma l \cos \theta = 0$ 、 $\Sigma l \sin \theta = 0$ なる故、前式は次のようになる。

$$\left. \begin{aligned} \Sigma l \mu \sin \theta - 6 \Sigma \frac{N}{A} l \cos \theta &= 0 \\ \Sigma l \mu \cos \theta + 6 \Sigma \frac{N}{A} l \sin \theta &= 0 \end{aligned} \right\} \dots \dots \dots (II)$$

(II) 式を 図-1 の任意の格間適用すれば(図-3)、橋の左半分に対して次の2式を得る。

図-3

$$\begin{aligned} \mu_{rv} &= \frac{l_{(r+1)(r+2)}}{l_{(r-1)r}} \mu_{(r+2)v} + \frac{\lambda}{l_{(r-1)r}} \tan \theta_{rl} \mu_{rl} - \frac{\lambda}{l_{(r-1)r}} \tan \theta_{ru} \mu_{ru} \\ &- 6 \frac{\lambda}{l_{(r-1)r}} \left\{ \frac{N_{(r-1)(r+1)}}{A_{(r-1)(r+1)}} - \frac{N_{r(r+2)}}{A_{r(r+2)}} \right\} \dots \dots \dots (III) \end{aligned}$$

$$\begin{aligned} \mu_{rl} - \mu_{ru} &+ 6 \left\{ \frac{N_{(r-1)(r+1)}}{A_{(r-1)(r+1)}} \tan \theta_{rl} + \frac{N_{(r+1)(r+2)}}{A_{(r+1)(r+2)}} \frac{l_{(r+1)(r+2)}}{\lambda} \right. \\ &\left. - \frac{N_{r(r+2)}}{A_{r(r+2)}} \tan \theta_{ru} - \frac{N_{(r-1)r}}{A_{(r-1)r}} \frac{l_{(r-1)r}}{\lambda} \right\} = 0 \dots \dots \dots (IV) \end{aligned}$$

橋の右半分に対しても同様な式を得る。

3. 軸 力

節点3及び4の直ぐ左側に 図-4 のような断面を仮定し、この断面より左側の釣合を考える。先づ節点4のまわりのモーメントの釣合を考えて整理すれば、 N_{13} は次のように各未知数、荷重 P, W 及び ϕ_1 の函数として表わす事が出来る。 ϕ_1 は支点1における節点回転角を $2E$ 倍したもので、構造が不備なため支点が回転した場合に適用出来るようにしたもので、既知の値とする。

$$N_{13} = F(\phi_2, \phi_3, \phi_4, \mu_{2l}, \mu_{2u}, M_1, H, A, P_2, W_2, \phi_1)$$

同様に節点3のまわりのモーメントの釣合を考えれば

$$N_{24} = F(\phi_2, \phi_3, \phi_4, \mu_{2l}, \mu_{2u}, M_1, H, A, P_2, W_2, \phi_1)$$

一般に弦材 $(r-1, r+1)$ 、 $(r, r+2)$ に対して節点 $r+1$ 及び $r+2$ の直ぐ左側に上と同様な断面を仮定して、この断面より左側の釣合を考えれば、下弦材 $(r-1, r+1)$ 及び上弦材 $(r, r+2)$ に対する軸力は次のような形で求まる。

$$\begin{aligned} N_{(r-1)(r+1)} &= F(\phi_{r-1}, \phi_r, \phi_{r+1}, \phi_{r+2}, \mu_{rl}, \mu_{ru}, M_1, H, A, P_2, P_3, \dots, \\ &P_r, W_2, W_3, \dots, W_r) \end{aligned}$$

$$N_{r(r+2)} = F(\phi_{r-1}, \phi_r, \phi_{r+1}, \phi_{r+2}, \mu_{rl}, \mu_{ru}, M_1, H, A, P_2, P_3, \dots, P_r, W_2, W_3, \dots, W_r)$$

垂直材に対しては、一般に r 節点に作用する力の垂直分力の釣合を考えれば次式を得る。

$$\begin{aligned} N_{(r-1)r} &= F(\phi_{r-3}, \phi_{r-2}, \phi_{r-1}, \phi_r, \phi_{r+1}, \phi_{r+2}, \mu_{(r-2)l}, \mu_{(r-2)u}, \mu_{ru}, M_1, H, A, P_2, P_3, \dots, \\ &P_r, W_2, W_3, \dots, W_r) \end{aligned}$$

橋の右半分に対しても同様に軸力を得る。

4. 垂直材の μ

3. で求めた N の値を (III) 式に入れれば、 μ_{rv} は次のような形で表わせる。

$$\mu_{rv} = F(\mu_{(r+2)r}, \phi_{r-1}, \phi_r, \phi_{r+1}, \phi_{r+2}, \mu_{rl}, \mu_{ru}, M_1, H, A, P_2, P_3, \dots, P_r, W_2, W_3, \dots, W_r)$$

この式を格間 $5-7(r=6)$ 、 $3-5(r=4)$ 、 $1-3(r=2)$ に順次適用してゆけば、垂直材 $(5,6)$ 、 $(3,4)$ 、 $(1,2)$ の μ 即ち μ_{65} 、 μ_{43} 、 μ_{21} を中央垂直材の μ {この場合垂直材 $(7,8)$ の μ }、弦材の μ, ϕ, M_1, H, A 及び荷重 P, W で

図-4

表わす事が出来る。

橋の右半分に對しても同様である。即ち未知数としての垂直材の μ は中央垂直材の μ のみとなり、未知数は此の例においては6個を減ずる事になる。

5. 方程式の作製 (表-1)

(A) 節点釣合方程式

節点1において $M_{12}=K_{12}(2\theta_1+\phi_2+\mu_{2v})$, $M_{13}=K_{13}(2\theta_1+\phi_3+\mu_{3l})$, $M_1+M_{12}+M_{13}=0$ より (1) 式を得

表-1 連立方程式表

Table of Simultaneous Equations

式	[M] ₁	[M] ₂	[M] ₃	[M] ₄	[M] ₅	[M] ₆	[M] ₇	[M] ₈	[M] ₉	[M] ₁₀	[M] ₁₁	[M] ₁₂	[M] ₁₃	[M] ₁₄	[M] ₁₅	[M] ₁₆	[M] ₁₇	[M] ₁₈	[M] ₁₉	[M] ₂₀	[M] ₂₁	[M] ₂₂	[M] ₂₃	[M] ₂₄	[M] ₂₅	[M] ₂₆	[M] ₂₇	[M] ₂₈	[M] ₂₉	[M] ₃₀	[M] ₃₁	[M] ₃₂	[M] ₃₃	[M] ₃₄	[M] ₃₅	[M] ₃₆	[M] ₃₇	[M] ₃₈	[M] ₃₉	[M] ₄₀	[M] ₄₁	[M] ₄₂	[M] ₄₃	[M] ₄₄	[M] ₄₅	[M] ₄₆	[M] ₄₇	[M] ₄₈	[M] ₄₉	[M] ₅₀	[M] ₅₁	[M] ₅₂	[M] ₅₃	[M] ₅₄	[M] ₅₅	[M] ₅₆	[M] ₅₇	[M] ₅₈	[M] ₅₉	[M] ₆₀	[M] ₆₁	[M] ₆₂	[M] ₆₃	[M] ₆₄	[M] ₆₅	[M] ₆₆	[M] ₆₇	[M] ₆₈	[M] ₆₉	[M] ₇₀	[M] ₇₁	[M] ₇₂	[M] ₇₃	[M] ₇₄	[M] ₇₅	[M] ₇₆	[M] ₇₇	[M] ₇₈	[M] ₇₉	[M] ₈₀	[M] ₈₁	[M] ₈₂	[M] ₈₃	[M] ₈₄	[M] ₈₅	[M] ₈₆	[M] ₈₇	[M] ₈₈	[M] ₈₉	[M] ₉₀	[M] ₉₁	[M] ₉₂	[M] ₉₃	[M] ₉₄	[M] ₉₅	[M] ₉₆	[M] ₉₇	[M] ₉₈	[M] ₉₉	[M] ₁₀₀	[M] ₁₀₁	[M] ₁₀₂	[M] ₁₀₃	[M] ₁₀₄	[M] ₁₀₅	[M] ₁₀₆	[M] ₁₀₇	[M] ₁₀₈	[M] ₁₀₉	[M] ₁₁₀	[M] ₁₁₁	[M] ₁₁₂	[M] ₁₁₃	[M] ₁₁₄	[M] ₁₁₅	[M] ₁₁₆	[M] ₁₁₇	[M] ₁₁₈	[M] ₁₁₉	[M] ₁₂₀	[M] ₁₂₁	[M] ₁₂₂	[M] ₁₂₃	[M] ₁₂₄	[M] ₁₂₅	[M] ₁₂₆	[M] ₁₂₇	[M] ₁₂₈	[M] ₁₂₉	[M] ₁₃₀	[M] ₁₃₁	[M] ₁₃₂	[M] ₁₃₃	[M] ₁₃₄	[M] ₁₃₅	[M] ₁₃₆	[M] ₁₃₇	[M] 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₃₈₈	[M] ₃₈₉	[M] ₃₉₀	[M] ₃₉₁	[M] ₃₉₂	[M] ₃₉₃	[M] ₃₉₄	[M] ₃₉₅	[M] ₃₉₆	[M] ₃₉₇	[M] ₃₉₈	[M] ₃₉₉	[M] ₄₀₀	[M] ₄₀₁	[M] ₄₀₂	[M] ₄₀₃	[M] ₄₀₄	[M] ₄₀₅	[M] ₄₀₆	[M] ₄₀₇	[M] ₄₀₈	[M] ₄₀₉	[M] ₄₁₀	[M] ₄₁₁	[M] ₄₁₂	[M] ₄₁₃	[M] ₄₁₄	[M] ₄₁₅	[M] ₄₁₆	[M] ₄₁₇	[M] ₄₁₈	[M] ₄₁₉	[M] ₄₂₀	[M] ₄₂₁	[M] ₄₂₂	[M] ₄₂₃	[M] ₄₂₄	[M] ₄₂₅	[M] ₄₂₆	[M] ₄₂₇	[M] ₄₂₈	[M] ₄₂₉	[M] ₄₃₀	[M] ₄₃₁	[M] ₄₃₂	[M] ₄₃₃	[M] ₄₃₄	[M] ₄₃₅	[M] ₄₃₆	[M] ₄₃₇	[M] ₄₃₈	[M] ₄₃₉	[M] ₄₄₀	[M] ₄₄₁	[M] ₄₄₂	[M] ₄₄₃	[M] ₄₄₄	[M] ₄₄₅	[M] ₄₄₆	[M] ₄₄₇	[M] ₄₄₈	[M] ₄₄₉	[M] ₄₅₀	[M] ₄₅₁	[M] ₄₅₂	[M] ₄₅₃	[M] ₄₅₄	[M] ₄₅₅	[M] ₄₅₆	[M] ₄₅₇	[M] ₄₅₈	[M] ₄₅₉	[M] ₄₆₀	[M] ₄₆₁	[M] ₄₆₂	[M] ₄₆₃	[M] ₄₆₄	[M] ₄₆₅	[M] ₄₆₆	[M] ₄₆₇	[M] ₄₆₈	[M] ₄₆₉	[M] ₄₇₀	[M] ₄₇₁	[M] ₄₇₂	[M] ₄₇₃	[M] ₄₇₄	[M] ₄₇₅	[M] ₄₇₆	[M] ₄₇₇	[M] ₄₇₈	[M] ₄₇₉	[M] ₄₈₀	[M] ₄₈₁	[M] ₄₈₂	[M] ₄₈₃	[M] ₄₈₄	[M] ₄₈₅	[M] ₄₈₆	[M] ₄₈₇	[M] ₄₈₈	[M] ₄₈₉	[M] ₄₉₀	[M] ₄₉₁	[M] ₄₉₂	[M] ₄₉₃	[M] ₄₉₄	[M] ₄₉₅	[M] ₄₉₆	[M] ₄₉₇	[M] ₄₉₈	[M] ₄₉₉	[M] ₅₀₀	[M] ₅₀₁	[M] ₅₀₂	[M] ₅₀₃	[M] ₅₀₄	[M] ₅₀₅	[M] ₅₀₆	[M] ₅₀₇	[M] ₅₀₈	[M] ₅₀₉	[M] ₅₁₀	[M] ₅₁₁	[M] ₅₁₂	[M] ₅₁₃	[M] ₅₁₄	[M] ₅₁₅	[M] ₅₁₆	[M] ₅₁₇	[M] ₅₁₈	[M] ₅₁₉	[M] ₅₂₀	[M] ₅₂₁	[M] ₅₂₂	[M] ₅₂₃	[M] ₅₂₄	[M] ₅₂₅	[M] ₅₂₆	[M] ₅₂₇	[M] ₅₂₈	[M] ₅₂₉	[M] ₅₃₀	[M] ₅₃₁	[M] ₅₃₂	[M] ₅₃₃	[M] ₅₃₄	[M] ₅₃₅	[M] ₅₃₆	[M] ₅₃₇	[M] ₅₃₈	[M] ₅₃₉	[M] ₅₄₀	[M] ₅₄₁	[M] ₅₄₂	[M] ₅₄₃	[M] ₅₄₄	[M] ₅₄₅	[M] ₅₄₆	[M] ₅₄₇	[M] ₅₄₈	[M] ₅₄₉	[M] ₅₅₀	[M] ₅₅₁	[M] ₅₅₂	[M] ₅₅₃	[M] ₅₅₄	[M] ₅₅₅	[M] ₅₅₆	[M] ₅₅₇	[M] ₅₅₈	[M] ₅₅₉	[M] ₅₆₀	[M] ₅₆₁	[M] ₅₆₂	[M] ₅₆₃	[M] ₅₆₄	[M] ₅₆₅	[M] ₅₆₆	[M] ₅₆₇	[M] ₅₆₈	[M] ₅₆₉	[M] ₅₇₀	[M] ₅₇₁	[M] ₅₇₂	[M] ₅₇₃	[M] ₅₇₄	[M] ₅₇₅	[M] ₅₇₆	[M] ₅₇₇	[M] ₅₇₈	[M] ₅₇₉	[M] ₅₈₀	[M] ₅₈₁	[M] ₅₈₂	[M] ₅₈₃	[M] ₅₈₄	[M] ₅₈₅	[M] ₅₈₆	[M] ₅₈₇	[M] ₅₈₈	[M] ₅₈₉	[M] ₅₉₀	[M] ₅₉₁	[M] ₅₉₂	[M] ₅₉₃	[M] ₅₉₄	[M] ₅₉₅	[M] ₅₉₆	[M] ₅₉₇	[M] ₅₉₈	[M] ₅₉₉	[M] ₆₀₀	[M] ₆₀₁	[M] ₆₀₂	[M] ₆₀₃	[M] ₆₀₄	[M] ₆₀₅	[M] ₆₀₆	[M] ₆₀₇	[M] ₆₀₈	[M] ₆₀₉	[M] ₆₁₀	[M] ₆₁₁	[M] ₆₁₂	[M] ₆₁₃	[M] ₆₁₄	[M] ₆₁₅	[M] ₆₁₆	[M] ₆₁₇	[M] ₆₁₈	[M] ₆₁₉	[M] ₆₂₀	[M] ₆₂₁	[M] ₆₂₂	[M] ₆₂₃	[M] ₆₂₄	[M] ₆₂₅	[M] ₆₂₆	[M] ₆₂₇	[M] ₆₂₈	[M] ₆₂₉	[M] ₆₃₀	[M] ₆₃₁	[M] ₆₃₂	[M] ₆₃₃	[M] ₆₃₄	[M] ₆₃₅	[M] ₆₃₆	[M] ₆₃₇	[M] ₆₃₈	[M] ₆₃₉	[M] ₆₄₀	[M] ₆₄₁	[M] ₆₄₂	[M] ₆₄₃	[M] ₆₄₄	[M] ₆₄₅	[M] ₆₄₆	[M] ₆₄₇	[M] ₆₄₈	[M] ₆₄₉	[M] ₆₅₀	[M] ₆₅₁	[M] ₆₅₂	[M] ₆₅₃	[M] ₆₅₄	[M] ₆₅₅	[M] ₆₅₆	[M] ₆₅₇	[M] ₆₅₈	[M] ₆₅₉	[M] ₆₆₀	[M] ₆₆₁	[M] ₆₆₂	[M] ₆₆₃	[M] ₆₆₄	[M] ₆₆₅	[M] ₆₆₆	[M] ₆₆₇	[M] ₆₆₈	[M] ₆₆₉	[M] ₆₇₀	[M] ₆₇₁	[M] ₆₇₂	[M] ₆₇₃	[M] ₆₇₄	[M] ₆₇₅	[M] ₆₇₆	[M] ₆₇₇	[M] ₆₇₈	[M] ₆₇₉	[M] ₆₈₀	[M] ₆₈₁	[M] ₆₈₂	[M] ₆₈₃	[M] ₆₈₄	[M] ₆₈₅	[M] ₆₈₆	[M] ₆₈₇	[M] ₆₈₈	[M] ₆₈₉	[M] ₆₉₀	[M] ₆₉₁	[M] ₆₉₂	[M] ₆₉₃	[M] ₆₉₄	[M] ₆₉₅	[M] ₆₉₆	[M] ₆₉₇	[M] ₆₉₈	[M] ₆₉₉	[M] ₇₀₀	[M] ₇₀₁	[M] ₇₀₂	[M] ₇₀₃	[M] ₇₀₄	[M] ₇₀₅	[M] ₇₀₆	[M] ₇₀₇	[M] ₇₀₈	[M] ₇₀₉	[M] ₇₁₀	[M] ₇₁₁	[M] ₇₁₂	[M] ₇₁₃	[M] ₇₁₄	[M] ₇₁₅	[M] ₇₁₆	[M] ₇₁₇	[M] ₇₁₈	[M] ₇₁₉	[M] ₇₂₀	[M] ₇₂₁	[M] ₇₂₂	[M] ₇₂₃	[M] ₇₂₄	[M] ₇₂₅	[M] ₇₂₆	[M] ₇₂₇	[M] ₇₂₈	[M] ₇₂₉	[M] ₇₃₀	[M] ₇₃₁	[M] ₇₃₂	[M] ₇₃₃	[M] ₇₃₄	[M] ₇₃₅	[M] ₇₃₆	[M] ₇₃₇	[M] ₇₃₈	[M] ₇₃₉	[M] ₇₄₀	[M] ₇₄₁	[M] ₇₄₂	[M] ₇₄₃	[M] ₇₄₄	[M] ₇₄₅	[M] ₇₄₆	[M] ₇₄₇	[M] ₇₄₈	[M] ₇₄₉	[M] ₇₅₀	[M] ₇₅₁	[M] ₇₅₂	[M] ₇₅₃	[M] ₇₅₄	[M] ₇₅₅	[M] ₇₅₆	[M] ₇₅₇	[M] ₇₅₈	[M] ₇₅₉	[M] ₇₆₀	[M] ₇₆₁	[M] ₇₆₂	[M] ₇₆₃	[M] ₇₆₄	[M] ₇₆₅	[M] ₇₆₆	[M] ₇₆₇	[M] ₇₆₈	[M] ₇₆₉	[M] ₇₇₀	[M] ₇₇₁	[M] ₇₇₂	[M] ₇₇₃	[M] ₇₇₄	[M] ₇₇₅	[M] ₇₇₆	[M] ₇₇₇	[M] ₇₇₈	[M] ₇₇₉	[M] ₇₈₀	[M] ₇₈₁	[M] ₇₈₂	[M] ₇₈₃	[M] ₇₈₄	[M] ₇₈₅	[M] ₇₈₆	[M] ₇₈₇	[M] ₇₈₈	[M] ₇₈₉	[M] ₇₉₀	[M] ₇₉₁	[M] ₇₉₂	[M] ₇₉₃	[M] ₇₉₄	[M] ₇₉₅	[M] ₇₉₆	[M] ₇₉₇	[M] ₇₉₈	[M] ₇₉₉	[M] ₈₀₀	[M] ₈₀₁	[M] ₈₀₂	[M] ₈₀₃	[M] ₈₀₄	[M] ₈₀₅	[M] ₈₀₆	[M] ₈₀₇	[M] ₈₀₈	[M] ₈₀₉	[M] ₈₁₀	[M] ₈₁₁	[M] ₈₁₂	[M] ₈₁₃	[M] ₈₁₄	[M] ₈₁₅	[M] ₈₁₆	[M] ₈₁₇	[M] ₈₁₈	[M] ₈₁₉	[M] ₈₂₀	[M] ₈₂₁	[M] ₈₂₂	[M] ₈₂₃	[M] ₈₂₄	[M] ₈₂₅	[M] ₈₂₆	[M] ₈₂₇	[M] ₈₂₈	[M] ₈₂₉	[M] ₈₃₀	[M] ₈₃₁	[M] ₈₃₂	[M] ₈₃₃	[M] ₈₃₄	[M] ₈₃₅	[M] ₈₃₆	[M] ₈₃₇	[M] ₈₃₈	[M] ₈₃₉	[M] ₈₄₀	[M] ₈₄₁	[M] ₈₄₂	[M] ₈₄₃	[M] ₈₄₄	[M] ₈₄₅	[M] ₈₄₆	[M] ₈₄₇	[M] ₈₄₈	[M] ₈₄₉	[M] ₈₅₀	[M] ₈₅₁	[M] ₈₅₂	[M] ₈₅₃	[M] ₈₅₄	[M] ₈₅₅	[M] ₈
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$$\begin{aligned}
& + \frac{K_{(r-1)(r+1)}}{A_{(r-1)(r+1)}} \sin \theta_{rl} \Big\} \\
\bar{B}_r(x) = & -6 \frac{K_{(x-1)x}}{l_{(x-1)x}} \lambda \left\{ \frac{K_{(r-1)(r+1)}}{l_{(r+1)(r+2)}} \left(\frac{1}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{1}{A_{r(r+2)} \cos \theta_{ru}} \right) + \frac{3}{\lambda} \frac{K_{(r-1)(r+1)}}{A_{(r-1)(r+1)}} \sin \theta_{rl} \right\} \\
\bar{C}_r(x) = & -6 \frac{K_{(x-1)x}}{l_{(x-1)x}} \lambda \left\{ 2 \frac{K_{(r-2)r}}{l_{(r-1)r}} \left(\frac{1}{A_{(r-3)(r-1)} \cos \theta_{(r-2)l}} + \frac{1}{A_{(r-2)r} \cos \theta_{(r-2)u}} \right) \right. \\
& + \frac{K_{r(r+2)}}{l_{(r+1)(r+2)}} \left(\frac{1}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{1}{A_{r(r+2)} \cos \theta_{ru}} \right) - \frac{3}{\lambda} \left(\frac{K_{(r-2)r}}{A_{(r-2)r}} \sin \theta_{(r-2)u} \right. \\
& \left. \left. + \frac{K_{r(r+2)}}{A_{r(r+2)}} \sin \theta_{ru} \right) \right\} \\
\bar{C}_r(x) = & -6 \frac{K_{(x-1)x}}{l_{(x-1)x}} \lambda \left\{ \frac{K_{r(r+2)}}{l_{(r+1)(r+2)}} \left(\frac{1}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{1}{A_{r(r+2)} \cos \theta_{ru}} \right) - \frac{3}{\lambda} \frac{K_{r(r+2)}}{A_{r(r+2)}} \sin \theta_{ru} \right\} \\
D_r(x) = & \frac{K_{(x-1)x}}{l_{(x-1)x}} \lambda \left[\tan \theta_{rl} - 6 \left\{ \frac{K_{(r-1)(r+1)}}{l_{(r+1)(r+2)}} \left(\frac{1}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{1}{A_{r(r+2)} \cos \theta_{ru}} \right) \right. \right. \\
& \left. \left. + \frac{2}{\lambda} \frac{K_{(r-1)(r+1)}}{A_{(r-1)(r+1)}} \sin \theta_{rl} \right\} \right] \\
E_r(x) = & -\frac{K_{(x-1)x}}{l_{(x-1)x}} \lambda \left[\tan \theta_{ru} + 6 \left\{ \frac{K_{r(r+2)}}{l_{(r+1)(r+2)}} \left(\frac{1}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{1}{A_{r(r+2)} \cos \theta_{ru}} \right) \right. \right. \\
& \left. \left. - \frac{2}{\lambda} \frac{K_{r(r+2)}}{A_{r(r+2)}} \sin \theta_{ru} \right\} \right] \\
F_r = & \frac{K_{(r-1)r}}{l_{(r-1)r}} l_{(n+1)(n+2)} \\
G_r = & 6 \frac{K_{(r-1)r}}{l_{(r-1)r}} \lambda \left\{ \frac{1}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{1}{A_{(r+1)(r+3)} \cos \theta_{(r+2)l}} + \dots + \frac{1}{A_{(n-1)(n+1)} \cos \theta_{nl}} \right. \\
& + \frac{\lambda}{l_{(r+1)(r+2)}} \left(\frac{1}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{1}{A_{r(r+2)} \cos \theta_{ru}} \right) (\tan \theta_{2l} + \tan \theta_{4l} + \dots + \tan \theta_{rl}) \\
& + \frac{\lambda}{l_{(r+3)(r+4)}} \left(\frac{1}{A_{(r+1)(r+3)} \cos \theta_{(r+2)l}} + \frac{1}{A_{(r+2)(r+4)} \cos \theta_{(r+2)u}} \right) (\tan \theta_{2l} + \tan \theta_{4l} + \dots \\
& \left. + \tan \theta_{(r+2)l}) + \dots + \frac{\lambda}{l_{(n+1)(n+2)}} \left(\frac{1}{A_{(n-1)(n+1)} \cos \theta_{nl}} + \frac{1}{A_{n(n+2)} \cos \theta_{nu}} \right) \right. \\
& \left. \times (\tan \theta_{2l} + \tan \theta_{4l} + \dots + \tan \theta_{nl}) \right\} \\
I_r = & -6 \frac{K_{(r-1)r}}{l_{(r-1)r}} \lambda^2 \left\{ \frac{r}{2} \left(\frac{1}{l_{(r+1)(r+2)}} \left(\frac{1}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{1}{A_{r(r+2)} \cos \theta_{ru}} \right) + \frac{\frac{r}{2} + 1}{l_{(r+3)(r+4)}} \right. \right. \\
& \times \left(\frac{1}{A_{(r+1)(r+3)} \cos \theta_{(r+2)l}} + \frac{1}{A_{(r+2)(r+4)} \cos \theta_{(r+2)u}} \right) + \dots + \frac{\frac{n}{2}}{l_{(n+1)(n+2)}} \left(\frac{1}{A_{(n-1)(n+1)} \cos \theta_{nl}} \right. \\
& \left. \left. + \frac{1}{A_{n(n+2)} \cos \theta_{nu}} \right) \right\} \\
\alpha_r = & -6 \frac{K_{(r-1)r}}{l_{(r-1)r}} \lambda^2 \left\{ \frac{r}{2} \left(\frac{1}{l_{(r+1)(r+2)}} \left(\frac{1}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{1}{A_{r(r+2)} \cos \theta_{ru}} \right) + \frac{\frac{r}{2} + 1}{l_{(r+3)(r+4)}} \right. \right. \\
& \times \left(\frac{1}{A_{(r+1)(r+3)} \cos \theta_{(r+2)l}} + \frac{1}{A_{(r+2)(r+4)} \cos \theta_{(r+2)u}} \right) + \dots + \frac{\frac{n}{2}}{l_{(n+1)(n+2)}} \left(\frac{1}{A_{(n-1)(n+1)} \cos \theta_{nl}} \right. \\
& \left. \left. + \frac{1}{A_{n(n+2)} \cos \theta_{nu}} \right) \right\} P_2 - 6 \frac{K_{(r-1)r}}{l_{(r-1)r}} \lambda^2 \left\{ \frac{\frac{r}{2} - 1}{l_{(r+1)(r+2)}} \left(\frac{1}{A_{(r-1)(r+1)} \cos \theta_{rl}} \right. \right. \\
& + \frac{1}{A_{r(r+2)} \cos \theta_{ru}} \Big) + \frac{\frac{r}{2}}{l_{(r+3)(r+4)}} \left(\frac{1}{A_{(r+1)(r+3)} \cos \theta_{(r+2)l}} + \frac{1}{A_{(r+2)(r+4)} \cos \theta_{(r+2)u}} \right) \\
& \left. + \dots + \frac{\frac{n}{2} - 1}{l_{(n+1)(n+2)}} \left(\frac{1}{A_{(n-1)(n+1)} \cos \theta_{nl}} + \frac{1}{A_{n(n+2)} \cos \theta_{nu}} \right) \right\} (P_3 + P_4) - \dots
\end{aligned}$$

$$-6 \frac{K_{(r-1)r}}{l_{(r-1)r}} \lambda^2 \left\{ \frac{1}{l_{(n+1)(n+2)}} \left(\frac{1}{A_{(n-1)(n+1)} \cos \theta_{nl}} + \frac{1}{A_{n(n+2)} \cos \theta_{nu}} \right) \right\} (P_{n-1} + P_n)$$

(B) 断面釣合方程式

図-4 において節点 3 及び 4 の直ぐ左側に仮定した断面より左側の力の垂直分力の釣合を考えて

$$N_{13} \sin \theta_{2l} + N_{24} \sin \theta_{2u} + S_{13} \cos \theta_{2l} + S_{24} \cos \theta_{2u} + A - P_2 = 0$$

之に 3. で求めた N_{13}, N_{24} を入れ、 S_{13}, S_{24} を φ, μ で表わして整理すれば (15) 式を得る。同様に節点 3' 及び 4' の直ぐ右側、節点 5 及び 6 の直ぐ左側、節点 5' 及び 6' の直ぐ右側等の断面に対する釣合を考えれば (16)~(20) 式を得る。

$$U_r = -(\tan \theta_{rl} - \tan \theta_{ru})$$

$$Q_{rl} = K_{(r-1)(r+1)} \left\{ (\tan \theta_{rl} - \tan \theta_{ru}) + 3 \frac{l_{(r+1)(r+2)}}{\lambda} \right\}$$

$$Q_{ru} = K_{r(r+2)} \left\{ (\tan \theta_{rl} - \tan \theta_{ru}) + 3 \frac{l_{(r+1)(r+2)}}{\lambda} \right\}$$

$$R_{rl} = K_{(r-1)(r+1)} \left\{ 2(\tan \theta_{rl} - \tan \theta_{ru}) + 3 \frac{l_{(r+1)(r+2)}}{\lambda} \right\}$$

$$R_{ru} = K_{r(r+2)} \left\{ 2(\tan \theta_{rl} - \tan \theta_{ru}) + 3 \frac{l_{(r+1)(r+2)}}{\lambda} \right\}$$

$$L_{rl} = K_{(r-1)(r+1)} \left\{ (\tan \theta_{rl} - \tan \theta_{ru}) + 2 \frac{l_{(r+1)(r+2)}}{\lambda} \right\}$$

$$L_{ru} = K_{r(r+2)} \left\{ (\tan \theta_{rl} - \tan \theta_{ru}) + 2 \frac{l_{(r+1)(r+2)}}{\lambda} \right\}$$

$$T_r = -\{l_{(r+1)(r+2)} \tan \theta_{rl} + \lambda (\tan \theta_{rl} - \tan \theta_{ru}) (\tan \theta_{2l} + \tan \theta_{4l} + \dots + \tan \theta_{rl})\}$$

$$S_r = l_{(r+1)(r+2)} + \frac{r}{2} \lambda (\tan \theta_{rl} - \tan \theta_{ru})$$

$$\gamma_r = \left\{ l_{(r+1)(r+2)} + \frac{r}{2} \lambda (\tan \theta_{rl} - \tan \theta_{ru}) \right\} P_2 + \left\{ l_{(r+1)(r+2)} + \left(\frac{r}{2} - 1 \right) \lambda (\tan \theta_{rl} - \tan \theta_{ru}) \right\} \\ \times (P_3 + P_4) + \dots + \{l_{(r+1)(r+2)} + \lambda (\tan \theta_{rl} - \tan \theta_{ru})\} (P_{r-1} + P_r)$$

(C) 格間釣合方程式

(IV) 式の N に 3. で求めた N の値を入れて整理すれば一般に次式を得る。

$$i_r [M_1] + a_{ri} \varphi_{r-3} + a_{ru} \varphi_{r-2} + b_{ri} \varphi_{r-1} + b_{ru} \varphi_r + c_{ri} \varphi_{r+1} + c_{ru} \varphi_{r+2} + d_{ri} \varphi_{r+3} + d_{ru} \varphi_{r+4} \\ + e_{ri} \mu_{(r-2)l} + e_{ru} \mu_{(r-2)u} + f_{ri} \mu_{rl} + f_{ru} \mu_{ru} + g_{ri} \mu_{(r+2)l} + g_{ru} \mu_{(r+2)u} + h_r [H] + k_r [A] = \varepsilon_r + \zeta_r$$

この式を格間 1-3($r=2$), 3-5($r=4$), 5-7($r=6$) に適用すれば夫々 (21), (23), (25) 式を得る。橋の右半分に対しても同様に (22), (24), (26) 式を得る。

$$i_r = -\left\{ \frac{1}{l_{(r+1)(r+2)}} \left(\frac{\tan \theta_{rl}}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{\tan \theta_{ru}}{A_{r(r+2)} \cos \theta_{ru}} \right) - \frac{1}{\lambda} \left(\frac{1}{A_{(r-1)r}} \tan \theta_{(r-2)u} \right. \right. \\ \left. \left. - \frac{1}{A_{(r+1)(r+2)}} \tan \theta_{ru} \right) + \frac{1}{\lambda} \left(\frac{l_{(r-1)r}}{l_{(r+1)(r+2)} A_{(r-1)r}} \tan \theta_{ru} - \frac{l_{(r+1)(r+2)}}{l_{(r+3)(r+4)} A_{(r+1)(r+2)}} \tan \theta_{(r+2)u} \right) \right\}$$

$$a_{rl} = -\frac{K_{(r-3)(r-1)}}{\lambda A_{(r-1)r}} \tan \theta_{(r-2)u}$$

$$a_{ru} = -\frac{K_{(r-2)r}}{\lambda A_{(r-1)r}} \left(\tan \theta_{(r-2)u} - 3 \frac{l_{(r-1)r}}{\lambda} \right)$$

$$b_{rl} = \frac{K_{(r-1)(r+1)}}{l_{(r+1)(r+2)} \left(\frac{\tan \theta_{rl}}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{\tan \theta_{ru}}{A_{r(r+2)} \cos \theta_{ru}} \right) + 3 \frac{K_{(r-1)(r+1)}}{\lambda A_{(r-1)(r+1)}} \sin \theta_{rl} \tan \theta_{rl} \\ - 2 \frac{K_{(r-3)(r-1)}}{\lambda A_{(r-1)(r+1)}} \tan \theta_{(r-2)u} + \frac{K_{(r-1)(r+1)}}{\lambda} \left(\frac{1}{A_{(r+1)(r+2)}} + \frac{l_{(r-1)r}}{l_{(r+1)(r+2)} A_{(r-1)r}} \right) \tan \theta_{ru}$$

$$b_{ru} = \frac{K_{r(r+2)}}{l_{(r+1)(r+2)} \left(\frac{\tan \theta_{rl}}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{\tan \theta_{ru}}{A_{r(r+2)} \cos \theta_{ru}} \right) - 3 \frac{K_{r(r+2)}}{\lambda A_{r(r+2)}} \sin \theta_{ru} \tan \theta_{ru} \\ - 2 \frac{K_{(r-2)r}}{\lambda A_{(r-1)r}} \tan \theta_{(r-2)u} + \frac{K_{r(r+2)}}{\lambda} \left(\frac{1}{A_{(r+1)(r+2)}} + \frac{l_{(r-1)r}}{l_{(r+1)(r+2)} A_{(r-1)r}} \right) \tan \theta_{ru} \\ + 3 \frac{K_{(r-2)r} l_{(r-1)r}}{\lambda^2 A_{(r-1)r}} - 3 \frac{K_{r(r+2)}}{\lambda^2} \left(\frac{l_{(r-1)r}}{A_{(r-1)r}} + \frac{l_{(r+1)(r+2)}}{A_{(r+1)(r+2)}} \right)$$

$$\begin{aligned}
e_{rl} &= 2 \frac{K_{(r-1)(r+1)}}{l_{(r+1)(r+2)}} \left(\frac{\tan \theta_{rl}}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{\tan \theta_{ru}}{A_{r(r+2)} \cos \theta_{ru}} \right) + 3 \frac{K_{(r-1)(r+1)}}{\lambda A_{(r-1)(r+1)}} \sin \theta_{rl} \tan \theta_{rl} \\
&\quad + 2 \frac{K_{(r-1)(r+1)}}{\lambda} \left(\frac{1}{A_{(r+1)(r+2)}} + \frac{l_{(r-1)r}}{l_{(r+1)(r+2)} A_{(r-1)r}} \right) \tan \theta_{ru} - \frac{K_{(r+1)(r+3)} l_{(r+1)(r+2)}}{l_{(r+3)(r+4)} \lambda A_{(r+1)(r+2)}} \tan \theta_{(r+2)u} \\
e_{ru} &= 2 \frac{K_{r(r+2)}}{l_{(r+1)(r+2)}} \left(\frac{\tan \theta_{rl}}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{\tan \theta_{ru}}{A_{r(r+2)} \cos \theta_{ru}} \right) - 3 \frac{K_{r(r+2)}}{\lambda A_{r(r+2)}} \sin \theta_{ru} \tan \theta_{ru} \\
&\quad + 2 \frac{K_{r(r+2)}}{\lambda} \left(\frac{1}{A_{(r+1)(r+2)}} + \frac{l_{(r-1)r}}{l_{(r+1)(r+2)} A_{(r-1)r}} \right) \tan \theta_{ru} - \frac{K_{(r+2)(r+4)} l_{(r+1)(r+2)}}{l_{(r+3)(r+4)} \lambda A_{(r+1)(r+2)}} \tan \theta_{(r+2)u} \\
&\quad - 3 \frac{K_{r(r+2)}}{\lambda} \left(\frac{l_{(r-1)r}}{A_{(r-1)r}} + \frac{l_{(r+1)(r+2)}}{A_{(r+1)(r+2)}} \right) + 3 \frac{K_{(r+2)(r+4)} l_{(r+1)(r+2)}}{\lambda^2 A_{(r+1)(r+2)}} \\
d_{rl} &= -2 \frac{K_{(r+1)(r+3)} l_{(r+1)(r+2)}}{l_{(r+3)(r+4)} \lambda A_{(r+1)(r+2)}} \tan \theta_{(r+2)u} \\
d_{ru} &= \frac{K_{(r+2)(r+4)}}{A_{(r+1)(r+2)}} \left(-\frac{2}{\lambda} \frac{l_{(r+1)(r+2)}}{l_{(r+3)(r+4)}} \tan \theta_{(r+2)u} + 3 \frac{l_{(r+1)(r+2)}}{\lambda^2} \right) \\
e_{rl} &= -\frac{K_{(r-3)(r-1)}}{\lambda A_{(r-1)r}} \tan \theta_{(r-2)u} \\
e_{ru} &= \frac{K_{(r-2)r}}{A_{(r-1)r}} \left(-\frac{1}{\lambda} \tan \theta_{(r-2)u} + 2 \frac{l_{(r-1)r}}{\lambda^2} \right) \\
f_{rl} &= \frac{1}{6} + \frac{K_{(r-1)(r+1)}}{l_{(r+1)(r+2)}} \left(\frac{\tan \theta_{rl}}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{\tan \theta_{ru}}{A_{r(r+2)} \cos \theta_{ru}} \right) + 2 \frac{K_{(r-1)(r+1)}}{\lambda A_{(r-1)(r+1)}} \sin \theta_{rl} \tan \theta_{rl} \\
&\quad + \frac{K_{(r-1)(r+1)}}{\lambda} \left(\frac{1}{A_{(r+1)(r+2)}} + \frac{l_{(r-1)r}}{l_{(r+1)(r+2)} A_{(r-1)r}} \right) \tan \theta_{ru} \\
f_{ru} &= -\frac{1}{6} + \frac{K_{r(r+2)}}{l_{(r+1)(r+2)}} \left(\frac{\tan \theta_{rl}}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{\tan \theta_{ru}}{A_{r(r+2)} \cos \theta_{ru}} \right) - 2 \frac{K_{r(r+2)}}{\lambda A_{r(r+2)}} \sin \theta_{ru} \tan \theta_{ru} \\
&\quad + \frac{K_{r(r+2)}}{\lambda} \left(\frac{1}{A_{(r+1)(r+2)}} + \frac{l_{(r-1)r}}{l_{(r+1)(r+2)} A_{(r-1)r}} \right) \tan \theta_{ru} - 2 \frac{K_{r(r+2)}}{\lambda^2} \left(\frac{l_{(r-1)r}}{A_{(r-1)r}} + \frac{l_{(r+1)(r+2)}}{A_{(r+1)(r+2)}} \right) \\
g_{rl} &= -\frac{K_{(r+1)(r+3)} l_{(r+1)(r+2)}}{l_{(r+3)(r+4)} \lambda A_{(r+1)(r+2)}} \tan \theta_{(r+2)u} \\
g_{ru} &= \frac{K_{(r+2)(r+4)}}{A_{(r+1)(r+2)}} \left(-\frac{1}{\lambda} \frac{l_{(r+1)(r+2)}}{l_{(r+3)(r+4)}} \tan \theta_{(r+2)u} + 2 \frac{l_{(r+1)(r+2)}}{\lambda^2} \right) \\
h_r &= -\frac{\tan \theta_{rl}}{A_{(r-1)(r+1)} \cos \theta_{rl}} - \frac{\lambda}{l_{(r+1)(r+2)}} \left(\frac{\tan \theta_{rl}}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{\tan \theta_{ru}}{A_{r(r+2)} \cos \theta_{ru}} \right) \\
&\quad \times (\tan \theta_{2l} + \tan \theta_{4l} + \dots + \tan \theta_{rl}) + \frac{\tan \theta_{(r-2)u}}{A_{(r-1)r}} (\tan \theta_{2l} + \tan \theta_{4l} + \dots + \tan \theta_{(r-2)l}) \\
&\quad - \left(\frac{1}{A_{(r+1)(r+2)}} + \frac{l_{(r-1)r}}{l_{(r+1)(r+2)} A_{(r-1)r}} \right) \tan \theta_{ru} (\tan \theta_{2l} + \tan \theta_{4l} + \dots + \tan \theta_{rl}) \\
&\quad + \frac{l_{(r+1)(r+2)}}{l_{(r+3)(r+4)} A_{(r+1)(r+2)}} \tan \theta_{(r+2)u} (\tan \theta_{2l} + \tan \theta_{4l} + \dots + \tan \theta_{(r+2)l}) \\
k_r &= \frac{r}{2} \lambda \left(\frac{\tan \theta_{rl}}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{\tan \theta_{ru}}{A_{r(r+2)} \cos \theta_{ru}} \right) - \left(\frac{r}{2} - 1 \right) \frac{\tan \theta_{(r-2)u}}{A_{(r-1)r}} \\
&\quad + \frac{r}{2} \left(\frac{1}{A_{(r+1)(r+2)}} + \frac{l_{(r-1)r}}{l_{(r+1)(r+2)} A_{(r-1)r}} \right) \tan \theta_{ru} - \left(\frac{r}{2} + 1 \right) \frac{l_{(r+1)(r+2)} \tan \theta_{(r+2)u}}{l_{(r+3)(r+4)} A_{(r+1)(r+2)}} \\
\varepsilon_r &= \left\{ \frac{r}{2} \lambda \left(\frac{\tan \theta_{rl}}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{\tan \theta_{ru}}{A_{r(r+2)} \cos \theta_{ru}} \right) - \left(\frac{r}{2} - 1 \right) \frac{\tan \theta_{(r-2)u}}{A_{(r-1)r}} \right. \\
&\quad \left. + \frac{r}{2} \left(\frac{1}{A_{(r+1)(r+2)}} + \frac{l_{(r-1)r}}{l_{(r+1)(r+2)} A_{(r-1)r}} \right) \tan \theta_{ru} - \left(\frac{r}{2} + 1 \right) \frac{l_{(r+1)(r+2)} \tan \theta_{(r+2)u}}{l_{(r+3)(r+4)} A_{(r+1)(r+2)}} \right\} P_2 \\
&\quad + \left\{ \left(\frac{r}{2} - 1 \right) \lambda \left(\frac{\tan \theta_{rl}}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{\tan \theta_{ru}}{A_{r(r+2)} \cos \theta_{ru}} \right) - \left(\frac{r}{2} - 2 \right) \frac{\tan \theta_{(r-2)u}}{A_{(r-1)r}} \right. \\
&\quad \left. + \left(\frac{r}{2} - 1 \right) \left(\frac{1}{A_{(r+1)(r+2)}} + \frac{l_{(r-1)r}}{l_{(r+1)(r+2)} A_{(r-1)r}} \right) \tan \theta_{ru} - \frac{r}{2} \frac{l_{(r+1)(r+2)} \tan \theta_{(r+2)u}}{l_{(r+3)(r+4)} A_{(r+1)(r+2)}} \right\} (P_3 + P_4)
\end{aligned}$$

$$\begin{aligned}
& + \cdots + \left\{ \frac{2\lambda}{l_{(r+1)(r+2)}} \left(\frac{\tan\theta_{rl}}{A_{(r-1)(r+1)\cos\theta_{rl}}} + \frac{\tan\theta_{ru}}{A_{r(r+2)\cos\theta_{ru}}} \right) - \frac{\tan\theta_{(r-2)u}}{A_{(r-1)r}} + 2 \left(\frac{1}{A_{(r+1)(r+2)}} \right. \right. \\
& \left. \left. + \frac{l_{(r-1)r}}{l_{(r+1)(r+2)}A_{(r-1)r}} \right) \tan\theta_{ru} - 3 \frac{l_{(r+1)(r+2)}\tan\theta_{(r+2)u}}{l_{(r+3)(r+4)}A_{(r+1)(r+2)}} \right\} (P_{r-3} + P_{r-2}) \\
& + \left\{ \frac{\lambda}{l_{(r+1)(r+2)}} \left(\frac{\tan\theta_{rl}}{A_{(r-1)(r+1)\cos\theta_{rl}}} + \frac{\tan\theta_{ru}}{A_{r(r+2)\cos\theta_{ru}}} \right) + \left(\frac{1}{A_{(r+1)(r+2)}} \right. \right. \\
& \left. \left. + \frac{l_{(r-1)r}}{l_{(r+1)(r+2)}A_{(r-1)r}} \right) \tan\theta_{ru} - 2 \frac{l_{(r+1)(r+2)}\tan\theta_{(r+2)u}}{l_{(r+3)(r+4)}A_{(r+1)(r+2)}} \right\} P_{r-1} + \left\{ \frac{\lambda}{l_{(r+1)(r+2)}} \right. \\
& \times \left(\frac{\tan\theta_{rl}}{A_{(r-1)(r+1)\cos\theta_{rl}}} + \frac{\tan\theta_{ru}}{A_{r(r+2)\cos\theta_{ru}}} \right) + \left(\frac{1}{A_{(r+1)(r+2)}} + \frac{l_{(r-1)r}}{l_{(r+1)(r+2)}A_{(r-1)r}} \right) \tan\theta_{ru} \\
& \left. - 2 \frac{l_{(r+1)(r+2)}\tan\theta_{(r+2)u}}{l_{(r+3)(r+4)}A_{(r+1)(r+2)}} - \frac{l_{(r-1)r}}{\lambda A_{(r-1)r}} \right\} P_r - \frac{l_{(r+1)(r+2)}\tan\theta_{(r+2)u}}{l_{(r+3)(r+4)}A_{(r+1)(r+2)}} P_{r+1} \\
& + \left\{ - \frac{l_{(r+1)(r+2)}\tan\theta_{(r+2)u}}{l_{(r+3)(r+4)}A_{(r+1)(r+2)}} + \frac{l_{(r+1)(r+2)}}{\lambda A_{(r+1)(r+2)}} \right\} P_{r+2}
\end{aligned}$$

(D) 垂直材釣合方程式

垂直材の上端の剪断力の釣合を考えて

$$\begin{aligned}
& \frac{M_{12} + M_{21}}{l_{12}} + \frac{M'_{1'2'} + M'_{2'1'}}{l'_{1'2'}} + \frac{M_{34} + M_{43}}{l_{34}} + \frac{M'_{3'4'} + M'_{4'3'}}{l'_{3'4'}} + \frac{M_{56} + M_{65}}{l_{56}} + \frac{M'_{5'6'} + M'_{6'5'}}{l'_{5'6'}} \\
& + \frac{M_{78} + M_{87}}{l_{78}} = -W_2 - W'_2 - W_4 - W'_4 - W_6 - W'_6 - W_8
\end{aligned}$$

この式の M を ϕ , μ で表わして整理すれば (27) 式を得る。

$$\begin{aligned}
w_r &= 4\lambda \left\{ \frac{1}{l_{34}} \frac{K_{12}}{l_{12}^2} \left(\frac{1}{A_{13}\cos\theta_{2l}} + \frac{1}{A_{24}\cos\theta_{2u}} \right) + \frac{1}{l_{56}} \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} \right) \left(\frac{1}{A_{35}\cos\theta_{4l}} + \frac{1}{A_{46}\cos\theta_{4u}} \right) + \cdots \right. \\
& \left. + \frac{1}{l_{(n+1)(n+2)}} \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \cdots + \frac{K_{(n-1)n}}{l_{(n-1)n}^2} \right) \left(\frac{1}{A_{(n-1)(n+1)\cos\theta_{nl}}} + \frac{1}{A_{n(n+2)\cos\theta_{nu}}} \right) \right\} \\
m_{rl} &= \frac{K_{(r-1)r}}{l_{(r-1)r}} - 8 \frac{K_{(r-3)(r-1)}}{l_{(r-1)r}} \lambda \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \cdots + \frac{K_{(r-3)(r-2)}}{l_{(r-3)(r-2)}^2} \right) \left(\frac{1}{A_{(r-3)(r-1)\cos\theta_{(r-2)l}}} \right. \\
& \left. + \frac{1}{A_{(r-2)r\cos\theta_{(r-2)u}}} \right) - 4 \frac{K_{(r-1)(r+1)}}{l_{(r+1)(r+2)}} \lambda \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \cdots + \frac{K_{(r-1)r}}{l_{(r-1)r}^2} \right) \left(\frac{1}{A_{(r-1)(r+1)\cos\theta_{rl}}} \right. \\
& \left. + \frac{1}{A_{r(r+2)\cos\theta_{ru}}} \right) - 12 \frac{K_{(r-3)(r-1)}}{A_{(r-3)(r-1)}} \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \cdots + \frac{K_{(r-3)(r-2)}}{l_{(r-3)(r-2)}^2} \right) \sin\theta_{(r-2)l} \\
& - 12 \frac{K_{(r-1)(r+1)}}{A_{(r-1)(r+1)}} \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \cdots + \frac{K_{(r-1)r}}{l_{(r-1)r}^2} \right) \sin\theta_{rl} \\
m_{ru} &= \frac{K_{(r-1)r}}{l_{(r-1)r}} - 8 \frac{K_{(r-2)r}}{l_{(r-1)r}} \lambda \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \cdots + \frac{K_{(r-3)(r-2)}}{l_{(r-3)(r-2)}^2} \right) \left(\frac{1}{A_{(r-3)(r-1)\cos\theta_{(r-2)l}}} \right. \\
& \left. + \frac{1}{A_{(r-2)r\cos\theta_{(r-2)u}}} \right) - 4 \frac{K_{r(r+2)}}{l_{(r+1)(r+2)}} \lambda \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \cdots + \frac{K_{(r-1)r}}{l_{(r-1)r}^2} \right) \left(\frac{1}{A_{(r-1)(r+1)\cos\theta_{rl}}} \right. \\
& \left. + \frac{1}{A_{r(r+2)\cos\theta_{ru}}} \right) + 12 \frac{K_{(r-2)r}}{A_{(r-2)r}} \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \cdots + \frac{K_{(r-3)(r-2)}}{l_{(r-3)(r-2)}^2} \right) \sin\theta_{(r-2)u} \\
& + 12 \frac{K_{r(r+2)}}{A_{r(r+2)}} \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \cdots + \frac{K_{(r-1)r}}{l_{(r-1)r}^2} \right) \sin\theta_{ru} \\
m_{(n+2)l} &= m_{(n+2)l} + m_{(n+2)l}' - \frac{K_{(n+1)'(n+2)'}}{l_{(n+1)'(n+2)'}} \\
m_{(n+2)u} &= m_{(n+2)u} + m_{(n+2)u}' - \frac{K_{(n+1)'(n+2)'}}{l_{(n+1)'(n+2)'}} \\
n_{rl} &= \frac{2}{3} \lambda \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \cdots + \frac{K_{(r-1)r}}{l_{(r-1)r}^2} \right) \tan\theta_{rl} - 4 \frac{K_{(r-1)(r+1)}}{l_{(r+1)(r+2)}} \lambda \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \cdots \right. \\
& \left. + \frac{K_{(r-1)r}}{l_{(r-1)r}^2} \right) \left(\frac{1}{A_{(r-1)(r+1)\cos\theta_{rl}}} + \frac{1}{A_{r(r+2)\cos\theta_{ru}}} \right) - 8 \frac{K_{(r-1)(r+1)}}{A_{(r-1)(r+1)}} \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} \right. \\
& \left. + \cdots + \frac{K_{(r-1)r}}{l_{(r-1)r}^2} \right) \sin\theta_{rl} \\
n_{ru} &= -\frac{2}{3} \lambda \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \cdots + \frac{K_{(r-1)r}}{l_{(r-1)r}^2} \right) \tan\theta_{ru} - 4 \frac{K_{r(r+2)}}{l_{(r+1)(r+2)}} \lambda \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \cdots + \frac{K_{(r-1)r}}{l_{(r-1)r}^2} \right)
\end{aligned}$$

$$\begin{aligned}
& \times \left(\frac{1}{A_{(r-1)(r+1)} \cos \theta_{rl}} + \frac{1}{A_{r(r+2)} \cos \theta_{ru}} \right) + 8 \frac{K_{r(r+2)}}{A_{r(r+2)}} \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \dots + \frac{K_{(r-1)r}}{l_{(r-1)r}^2} \right) \sin \theta_{ru} \\
z = & \frac{2}{3} \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{1'2'}}{l_{1'2'}^2} + \frac{K_{34}}{l_{34}^2} + \frac{K_{3'4'}}{l_{3'4'}^2} + \dots + \frac{K_{(n-1)n}}{l_{(n-1)n}^2} + \frac{K_{(n-1)'n'}}{l_{(n-1)'n'}^2} + \frac{K_{(n+1)(n+2)}}{l_{(n+1)(n+2)}^2} \right) l_{(n+1)(n+2)} \\
u = & 4\lambda \left\{ \frac{K_{12}}{l_{12}^2} - \frac{1}{A_{13} \cos \theta_{2l}} + \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} \right) \frac{1}{A_{35} \cos \theta_{4l}} + \dots + \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \dots + \frac{K_{(n-1)n}}{l_{(n-1)n}^2} \right) \right. \\
& \times \frac{1}{A_{(n-1)(n+1)} \cos \theta_{nl}} + \frac{\lambda}{l_{34}} \frac{K_{12}}{l_{12}^2} \left(\frac{1}{A_{13} \cos \theta_{2l}} + \frac{1}{A_{24} \cos \theta_{2u}} \right) \tan \theta_{2l} + \frac{\lambda}{l_{56}} \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} \right) \\
& \times \left(\frac{1}{A_{35} \cos \theta_{4l}} + \frac{1}{A_{46} \cos \theta_{4u}} \right) (\tan \theta_{2l} + \tan \theta_{4l}) + \dots + \frac{\lambda}{l_{(n+1)(n+2)}} \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \dots \right. \\
& \left. + \frac{K_{(n-1)n}}{l_{(n-1)n}^2} \right) \left(\frac{1}{A_{(n-1)(n+1)} \cos \theta_{nl}} + \frac{1}{A_{n(n+2)} \cos \theta_{nu}} \right) (\tan \theta_{2l} + \tan \theta_{4l} + \dots \\
& \left. + \tan \theta_{nl}) \right\} - 4\lambda \left\{ \frac{K_{1'2'}}{l_{1'2'}^2} - \frac{1}{A_{1'3'} \cos \theta_{2'l}} + \dots + \left(\frac{K_{1'2'}}{l_{1'2'}^2} + \frac{K_{3'4'}}{l_{3'4'}^2} + \dots + \frac{K_{(n-1)'n'}}{l_{(n-1)'n'}^2} \right) \right. \\
& \times \frac{1}{A_{(n-1)'(n+1)' \cos \theta_{n'l}} + \frac{\lambda}{l_{3'4'}} \frac{K_{1'2'}}{l_{1'2'}^2} \left(\frac{1}{A_{1'3'} \cos \theta_{2'l}} + \frac{1}{A_{2'4'} \cos \theta_{2'u}} \right) \tan \theta_{2'l} + \dots \\
& \left. + \frac{\lambda}{l_{(n+1)'(n+2)'}} \left(\frac{K_{1'2'}}{l_{1'2'}^2} + \frac{K_{3'4'}}{l_{3'4'}^2} + \dots + \frac{K_{(n-1)'n'}}{l_{(n-1)'n'}^2} \right) \left(\frac{1}{A_{(n-1)'(n+1)' \cos \theta_{n'l}} \right. \right. \\
& \left. \left. + \frac{1}{A_{n'(n+2)'} \cos \theta_{n'u}} \right) (\tan \theta_{2'l} + \tan \theta_{4'l} + \dots + \tan \theta_{n'l}) \right\} \\
v_r = & -4\lambda^2 \left\{ \frac{1}{l_{34}} \frac{K_{12}}{l_{12}^2} \left(\frac{1}{A_{13} \cos \theta_{2l}} + \frac{1}{A_{24} \cos \theta_{2u}} \right) + \frac{2}{l_{56}} \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} \right) \left(\frac{1}{A_{35} \cos \theta_{4l}} + \frac{1}{A_{46} \cos \theta_{4u}} \right) \right. \\
& \left. + \dots + \frac{n}{l_{(n+1)(n+2)}} \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \dots + \frac{K_{(n-1)n}}{l_{(n-1)n}^2} \right) \left(\frac{1}{A_{(n-1)(n+1)} \cos \theta_{nl}} + \frac{1}{A_{n(n+2)} \cos \theta_{nu}} \right) \right\} \\
\eta = & -4\lambda^2 \left\{ \frac{1}{l_{34}} \frac{K_{12}}{l_{12}^2} \left(\frac{1}{A_{13} \cos \theta_{2l}} + \frac{1}{A_{24} \cos \theta_{2u}} \right) + \frac{2}{l_{56}} \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} \right) \left(\frac{1}{A_{35} \cos \theta_{4l}} + \frac{1}{A_{46} \cos \theta_{4u}} \right) \right. \\
& \left. + \dots + \frac{n}{l_{(n+1)(n+2)}} \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \dots + \frac{K_{(n-1)n}}{l_{(n-1)n}^2} \right) \left(\frac{1}{A_{(n-1)(n+1)} \cos \theta_{nl}} \right. \right. \\
& \left. \left. + \frac{1}{A_{n(n+2)} \cos \theta_{nu}} \right) \right\} P_2 - 4\lambda^2 \left\{ \frac{1}{l_{56}} \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} \right) \left(\frac{1}{A_{35} \cos \theta_{4l}} + \frac{1}{A_{46} \cos \theta_{4u}} \right) \right. \\
& \left. + \frac{2}{l_{78}} \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \frac{K_{56}}{l_{56}^2} \right) \left(\frac{1}{A_{57} \cos \theta_{6l}} + \frac{1}{A_{68} \cos \theta_{6u}} \right) + \dots + \frac{n-1}{l_{(n+1)(n+2)}} \right. \\
& \times \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \dots + \frac{K_{(n-1)n}}{l_{(n-1)n}^2} \right) \left(\frac{1}{A_{(n-1)(n+1)} \cos \theta_{nl}} + \frac{1}{A_{n(n+2)} \cos \theta_{nu}} \right) \left. \right\} (P_3 + P_4) \\
& - \dots - 4\lambda^2 \left\{ \frac{1}{l_{(n+1)(n+2)}} \left(\frac{K_{12}}{l_{12}^2} + \frac{K_{34}}{l_{34}^2} + \dots + \frac{K_{(n-1)n}}{l_{(n-1)n}^2} \right) \right. \\
& \times \left(\frac{1}{A_{(n-1)(n+1)} \cos \theta_{nl}} + \frac{1}{A_{n(n+2)} \cos \theta_{nu}} \right) \left. \right\} (P_{n-1} + P_n) + 4\lambda^2 \left\{ \frac{1}{l_{3'4'}} \frac{K_{1'2'}}{l_{1'2'}^2} \left(\frac{1}{A_{1'3'} \cos \theta_{2'l}} \right. \right. \\
& \left. \left. + \frac{1}{A_{2'4'} \cos \theta_{2'u}} \right) + \frac{2}{l_{5'6'}} \left(\frac{K_{1'2'}}{l_{1'2'}^2} + \frac{K_{3'4'}}{l_{3'4'}^2} \right) \left(\frac{1}{A_{3'5'} \cos \theta_{4'l}} + \frac{1}{A_{4'6'} \cos \theta_{4'u}} \right) + \dots \right. \\
& \left. + \frac{n}{l_{(n+1)'(n+2)'}} \left(\frac{K_{1'2'}}{l_{1'2'}^2} + \frac{K_{3'4'}}{l_{3'4'}^2} + \dots + \frac{K_{(n-1)'n'}}{l_{(n-1)'n'}^2} \right) \left(\frac{1}{A_{(n-1)'(n+1)' \cos \theta_{n'l}} \right. \right. \\
& \left. \left. + \frac{1}{A_{n'(n+2)'} \cos \theta_{n'u}} \right) \right\} P_2' + \dots + 4\lambda^2 \left\{ \frac{1}{l_{(n+1)'(n+2)'}} \left(\frac{K_{1'2'}}{l_{1'2'}^2} + \frac{K_{3'4'}}{l_{3'4'}^2} + \dots \right. \right. \\
& \left. \left. + \frac{K_{(n-1)'n'}}{l_{(n-1)'n'}^2} \right) \left(\frac{1}{A_{(n-1)'(n+1)' \cos \theta_{n'l}} + \frac{1}{A_{n'(n+2)'} \cos \theta_{n'u}} \right) \right\} (P_{n-1}' + P_n')
\end{aligned}$$

(E) 支間釣合方程式

下弦材が図-5のように実線の位置から変形後点線の位置に移つたとし、支点の相対移動を次のように表わす。

図-5

水平方向 $A = L' - L$, 垂直方向 $\Omega = V' - V$.

(a) 水平方向:

$$\begin{aligned} L &= \sum \{ l_{(r-1)(r+1)} \cos \theta_{rl} + l_{(r-1)'(r+1)'} \cos \theta_{r'l} \} \\ L' &= \sum \{ l_{(r-1)(r+1)} + \Delta l_{(r-1)(r+1)} \cos (\theta_{rl} - \psi_{rl}) \\ &\quad + (l_{(r-1)'(r+1)'} + \Delta l_{(r-1)'(r+1)'}) \cos (\theta_{r'l} + \psi_{r'l}) \} \\ r &= 2, 4, 6, \dots, n \end{aligned}$$

$\psi_{rl}, \psi_{r'l}$ は極めて小さいから $\cos \psi_{rl} = 1, \sin \psi_{rl} = \psi_{rl},$
 $\cos \psi_{r'l} = 1, \sin \psi_{r'l} = \psi_{r'l}$ とおき, 更に $\Delta l_{(r-1)(r+1)},$

$\psi_{rl}, \Delta l_{(r-1)'(r+1)'} \psi_{r'l}$ を含む項は 2 次の微小量であるから省略すれば $L' - L$ は次のようになる。

$$L' - L = \sum \{ l_{(r-1)(r+1)} \psi_{rl} \sin \theta_{rl} + \Delta l_{(r-1)(r+1)} \cos \theta_{rl} - l_{(r-1)'(r+1)'} \psi_{r'l} \sin \theta_{r'l} + \Delta l_{(r-1)'(r+1)'} \cos \theta_{r'l} \} = A$$

この式に

$$\begin{aligned} l_{(r-1)(r+1)} &= \frac{\lambda}{\cos \theta_{rl}}, \quad l_{(r-1)'(r+1)'} = \frac{\lambda}{\cos \theta_{r'l}}, \quad \Delta l_{(r-1)(r+1)} = \frac{N_{(r-1)(r+1)}}{EA_{(r-1)(r+1)}} \frac{\lambda}{\cos \theta_{rl}} + \varepsilon t \frac{\lambda}{\cos \theta_{rl}}, \\ \Delta l_{(r-1)'(r+1)'} &= \frac{N_{(r-1)'(r+1)'}}{EA_{(r-1)'(r+1)'}} \frac{\lambda}{\cos \theta_{r'l}} + \varepsilon t \frac{\lambda}{\cos \theta_{r'l}} \end{aligned}$$

を入れ, 両辺に $-6E \frac{1}{\lambda}$ を乗ずれば

$$\sum \left\{ \tan \theta_{rl} \mu_{rl} - \tan \theta_{r'l} \mu_{r'l} - 6 \left(\frac{N_{(r-1)(r+1)}}{A_{(r-1)(r+1)}} + \frac{N_{(r-1)'(r+1)'}}{A_{(r-1)'(r+1)'}} \right) \right\} = 6E \left(n \varepsilon t - \frac{A}{\lambda} \right) \quad (r=2, 4, 6, \dots, n)$$

此の式に 3. で求めた N の値を入れて整理すれば (28) 式を得る。

$$\begin{aligned} x_r &= - \left(\frac{1}{A_{13} l_{34} \cos \theta_{2l}} + \frac{1}{A_{35} l_{56} \cos \theta_{4l}} + \dots + \frac{1}{A_{(n-1)(n+1)l(n+1)(n+2)} \cos \theta_{nl}} \right) \\ p_{rl} &= \frac{K_{(r-3)(r-1)}}{A_{(r-3)(r-1)}} \left(\frac{2}{l_{(r-3)r} \cos \theta_{(r-2)l}} + 3 \frac{\sin \theta_{(r-2)l}}{\lambda} \right) + \frac{K_{(r-1)(r+1)}}{A_{(r-1)(r+1)}} \left(\frac{1}{l_{(r+1)(r+2)} \cos \theta_{rl}} + 3 \frac{\sin \theta_{rl}}{\lambda} \right) \\ p_{ru} &= \frac{K_{(r-2)r}}{A_{(r-3)(r-1)}} \frac{2}{l_{(r-1)r} \cos \theta_{(r-2)l}} + \frac{K_{r(r+2)}}{A_{(r-1)(r+1)}} \frac{1}{l_{(r+1)(r+2)} \cos \theta_{rl}} \\ q_{rl} &= - \frac{1}{6} \tan \theta_{rl} + \frac{K_{(r-1)(r+1)}}{A_{(r-1)(r+1)}} \left(\frac{1}{l_{(r+1)(r+2)} \cos \theta_{rl}} + 2 \frac{\sin \theta_{rl}}{\lambda} \right) \\ q_{ru} &= \frac{K_{r(r+2)}}{A_{(r-1)(r+1)}} \frac{1}{l_{(r+1)(r+2)} \cos \theta_{rl}} \\ s &= \frac{1}{A_{13} \cos \theta_{2l}} + \frac{1}{A_{35} \cos \theta_{4l}} + \dots + \frac{1}{A_{(n-1)(n+1)} \cos \theta_{nl}} + \frac{\lambda}{A_{13} l_{34} \cos \theta_{2l}} \tan \theta_{2l} \\ &\quad + \frac{\lambda}{A_{35} l_{56} \cos \theta_{4l}} (\tan \theta_{2l} + \tan \theta_{4l}) + \dots + \frac{\lambda}{A_{(n-1)(n+1)l(n+1)(n+2)} \cos \theta_{nl}} (\tan \theta_{2l} \\ &\quad + \tan \theta_{4l} + \dots + \tan \theta_{nl}) + \frac{1}{A_{1'3'}' \cos \theta_{2'l}} + \dots + \frac{1}{A_{(n-1)'(n+1)'} \cos \theta_{n'l}} + \frac{\lambda}{A_{1'3'}' l_{3'4'}' \cos \theta_{2'l}} \\ &\quad \times \tan \theta_{2'l} + \dots + \frac{\lambda}{A_{(n-1)'(n+1)'l(n+1)'(n+2)'} \cos \theta_{n'l}} (\tan \theta_{2'l} + \tan \theta_{4'l} + \dots + \tan \theta_{n'l}) \\ t_r &= \lambda \left(\frac{1}{A_{13} l_{34} \cos \theta_{2l}} + \frac{2}{A_{35} l_{56} \cos \theta_{4l}} + \dots + \frac{n}{2} \frac{1}{A_{(n-1)(n+1)l(n+1)(n+2)} \cos \theta_{nl}} \right) \\ \xi &= - \lambda \left(\frac{1}{A_{13} l_{34} \cos \theta_{2l}} + \frac{2}{A_{35} l_{56} \cos \theta_{4l}} + \dots + \frac{n}{2} \frac{1}{A_{(n-1)(n+1)l(n+1)(n+2)} \cos \theta_{nl}} \right) P_2 \\ &\quad - \lambda \left(\frac{1}{A_{35} l_{56} \cos \theta_{4l}} + \frac{2}{A_{57} l_{78} \cos \theta_{6l}} + \dots + \frac{n}{2} - 1 \frac{1}{A_{(n-1)(n+1)l(n+1)(n+2)} \cos \theta_{nl}} \right) (P_3 + P_4) \\ &\quad - \dots - \lambda \left(\frac{1}{A_{(n-3)(n-1)l(n-1)n} \cos \theta_{(n-2)l}} + \frac{2}{A_{(n-1)(n+1)l(n+1)(n+2)} \cos \theta_{nl}} \right) (P_{n-3} + P_{n-2}) \\ &\quad - \lambda \left(\frac{1}{A_{(n-1)(n+1)l(n+1)n+2} \cos \theta_{nl}} \right) (P_{n-1} + P_n) - \lambda \left(\frac{1}{A_{1'3'}' l_{3'4'}' \cos \theta_{2'l}} + \frac{2}{A_{3'5'}' l_{5'6'}' \cos \theta_{4'l}} \right) \end{aligned}$$

$$+ \dots + \frac{\frac{n}{2}}{A_{(n-1)'(n+1)'l(n+1)'(n+2)'\cos\theta_{n'l}}} P_2' - \dots - \lambda \left(\frac{1}{A_{(n-1)'(n+1)'l(n+1)'(n+2)'\cos\theta_{n'l}}} \right) (P_{(n-1)'} + P_{n'})$$

(b) 垂直方向:

$$V = \Sigma (\ell_{(r-1)(r+1)} \sin \theta_{rl} - \ell_{(r-1)'(r+1)'} \sin \theta_{r'l'})$$

$$V' = \Sigma \{ (\ell_{(r-1)(r+1)} + \Delta \ell_{(r-1)(r+1)}) \sin (\theta_{rl} - \psi_{rl}) - (\ell_{(r-1)'(r+1)'} + \Delta \ell_{(r-1)'(r+1)'}) \sin (\theta_{r'l} + \psi_{r'l'}) \}$$

$$(r=2, 4, 6, \dots, n)$$

水平方向の場合と同様に $\cos \psi_{rl}=1$, $\sin \psi_{rl}=\psi_{rl}$, $\cos \psi_{r'l}=1$, $\sin \psi_{r'l}=\psi_{r'l}$ とおき, $\Delta \ell_{(r-1)(r+1)} \psi_{rl}$, $\Delta \ell_{(r-1)'(r+1)'} \psi_{r'l}$ を含む項を省略すれば $V'-V$ は次のようになる。

$$V'-V = \Sigma (-\ell_{(r-1)(r+1)} \psi_{rl} \cos \theta_{rl} + \Delta \ell_{(r-1)(r+1)} \sin \theta_{rl} - \ell_{(r-1)'(r+1)'} \psi_{r'l} \cos \theta_{r'l} - \Delta \ell_{(r-1)'(r+1)'} \sin \theta_{r'l}) = \Omega$$

この式に

$$\ell_{(r-1)(r+1)} = \frac{\lambda}{\cos \theta_{rl}}, \quad \ell_{(r-1)'(r+1)'} = \frac{\lambda}{\cos \theta_{r'l}}, \quad \Delta \ell_{(r-1)(r+1)} = \frac{N_{(r-1)(r+1)}}{EA_{(r-1)(r+1)}} \frac{\lambda}{\cos \theta_{rl}} + \varepsilon t \frac{\lambda}{\cos \theta_{rl}},$$

$$\Delta \ell_{(r-1)'(r+1)'} = \frac{N_{(r-1)'(r+1)'}}{EA_{(r-1)'(r+1)'}} \frac{\lambda}{\cos \theta_{r'l}} + \varepsilon t \frac{\lambda}{\cos \theta_{r'l}}$$

を入れ, 両辺に $6E \frac{1}{\lambda}$ を乗ずれば

$$\Sigma \left\{ \mu_{rl} + \mu_{r'l} + 6 \left(\frac{N_{(r-1)(r+1)}}{A_{(r-1)(r+1)}} \tan \theta_{rl} - \frac{N_{(r-1)'(r+1)'}}{A_{(r-1)'(r+1)'}} \tan \theta_{r'l} \right) \right\} = 6E \left\{ \frac{\Omega}{\lambda} - \varepsilon t \Sigma (\tan \theta_{rl} - \tan \theta_{r'l}) \right\}$$

$$(r=2, 4, 6, \dots, n)$$

この式に 3. で求めた N の値を入れて整理すれば(29)式を得る。

$$\begin{aligned} \bar{x}_r &= - \left(\frac{\tan \theta_{2l}}{A_{13} l_{34} \cos \theta_{2l}} + \frac{\tan \theta_{4l}}{A_{35} l_{56} \cos \theta_{4l}} + \dots + \frac{\tan \theta_{nl}}{A_{(n-1)(n+1)l(n+1)(n+2) \cos \theta_{nl}}} \right) \\ \bar{p}_{rl} &= \frac{K_{(r-3)(r-1)}}{A_{(r-3)(r-1)}} \left(\frac{2}{\ell_{(r-1)r} \cos \theta_{(r-2)l}} + 3 \frac{\sin \theta_{(r-2)l}}{\lambda} \right) \tan \theta_{(r-2)l} + \frac{K_{(r-1)(r+1)}}{A_{(r-1)(r+1)}} \\ &\quad \times \left(\frac{1}{\ell_{(r+1)(r+2) \cos \theta_{rl}} + 3 \frac{\sin \theta_{rl}}{\lambda}} \right) \tan \theta_{rl} \\ \bar{p}_{ru} &= \frac{K_{(r-2)r}}{A_{(r-3)(r-1)}} \frac{2}{\ell_{(r-1)r} \cos \theta_{(r-2)l}} \tan \theta_{(r-2)l} + \frac{K_{r(r+2)}}{A_{(r-1)(r+1)}} \frac{1}{\ell_{(r+1)(r+2) \cos \theta_{rl}}} \tan \theta_{rl} \\ \bar{q}_{rl} &= \frac{1}{6} + \frac{K_{(r-1)(r+1)}}{EA_{(r-1)(r+1)}} \left(\frac{1}{\ell_{(r+1)(r+2) \cos \theta_{rl}} + 2 \frac{\sin \theta_{rl}}{\lambda}} \right) \tan \theta_{rl} \\ \bar{q}_{ru} &= \frac{K_{r(r+2)}}{A_{(r-1)(r+1)}} \frac{1}{\ell_{(r+1)(r+2) \cos \theta_{rl}}} \tan \theta_{rl} \\ \bar{s} &= - \frac{\tan \theta_{2l}}{A_{13} \cos \theta_{2l}} - \frac{\tan \theta_{4l}}{A_{35} \cos \theta_{4l}} - \dots - \frac{\tan \theta_{nl}}{A_{(n-1)(n+1) \cos \theta_{nl}}} - \frac{\lambda \tan \theta_{2l}}{A_{13} l_{34} \cos \theta_{2l}} \tan \theta_{2l} \\ &\quad - \frac{\lambda \tan \theta_{4l}}{A_{35} l_{56} \cos \theta_{4l}} (\tan \theta_{2l} + \tan \theta_{4l}) - \dots - \frac{\lambda \tan \theta_{nl}}{A_{(n-1)(n+1)l(n+1)(n+2) \cos \theta_{nl}}} (\tan \theta_{2l} + \tan \theta_{4l} \\ &\quad + \dots + \tan \theta_{nl}) + \frac{\tan \theta_{2'l}}{A_{1'3'} l_{3'4'} \cos \theta_{2'l}} + \dots + \frac{\tan \theta_{n'l}}{A_{(n-1)'(n+1)' \cos \theta_{n'l}}} + \frac{\lambda \tan \theta_{2'l}}{A_{1'3'} l_{3'4'} \cos \theta_{2'l}} \tan \theta_{2'l} \\ &\quad + \dots + \frac{\lambda \tan \theta_{n'l}}{A_{(n-1)'(n+1)'l(n+1)'(n+2)' \cos \theta_{n'l}}} (\tan \theta_{2'l} + \tan \theta_{4'l} + \dots + \tan \theta_{n'l}) \\ \bar{t}_r &= \lambda \left(\frac{\tan \theta_{2l}}{A_{13} l_{34} \cos \theta_{2l}} + \frac{2 \tan \theta_{4l}}{A_{35} l_{56} \cos \theta_{4l}} + \dots + \frac{\frac{n}{2} \tan \theta_{nl}}{A_{(n-1)(n+1)l(n+1)(n+2) \cos \theta_{nl}}} \right) \\ \bar{\xi} &= \lambda \left(\frac{\tan \theta_{2l}}{A_{13} l_{34} \cos \theta_{2l}} + \frac{2 \tan \theta_{4l}}{A_{35} l_{56} \cos \theta_{4l}} + \dots + \frac{\frac{n}{2} \tan \theta_{nl}}{A_{(n-1)(n+1)l(n+1)(n+2) \cos \theta_{nl}}} \right) P_2 \\ &\quad + \lambda \left(\frac{\tan \theta_{4l}}{A_{35} l_{56} \cos \theta_{4l}} + \frac{2 \tan \theta_{6l}}{A_{57} l_{78} \cos \theta_{6l}} + \dots + \frac{\left(\frac{n}{2} - 1 \right) \tan \theta_{nl}}{A_{(n-1)(n+1)l(n+1)(n+2) \cos \theta_{nl}}} \right) (P_3 + P_4) \\ &\quad + \dots \end{aligned}$$

$$\begin{aligned}
 & +\lambda \left(\frac{\tan \theta_{(n-2)l}}{A_{(n-3)(n-1)l(n-1)n} \cos \theta_{(n-2)l}} + \frac{2 \tan \theta_{nl}}{A_{(n-1)(n+1)l(n+1)(n+2)} \cos \theta_{nl}} \right) (P_{n-3} + P_{n-2}) \\
 & +\lambda \left(\frac{\tan \theta_{nl}}{A_{(n-1)(n+1)l(n+1)(n+2)} \cos \theta_{nl}} \right) (P_{n-1} + P_n) - \lambda \left(\frac{\tan \theta_{2'l}}{A_{1'3'l'3'4'} \cos \theta_{2'l}} + \frac{2 \tan \theta_{4'l}}{A_{3'5'l'5'6'} \cos \theta_{4'l}} + \dots \right. \\
 & \left. + \frac{\frac{n}{2} \tan \theta_{n'l}}{A_{(n-1)'(n+1)'l(n+1)'(n+2)'} \cos \theta_{n'l}} \right) P_2' - \dots - \lambda \left(\frac{\tan \theta_{n'l}}{A_{(n-1)'(n+1)'l(n+1)'(n+2)'} \cos \theta_{n'l}} \right) \\
 & \times (P_{(n-1)'} + P_n')
 \end{aligned}$$

$$\Sigma(\tan \theta_{rl} - \tan \theta_{r'l}) = (\tan \theta_{2l} - \tan \theta_{2'l}) + (\tan \theta_{4l} - \tan \theta_{4'l}) + \dots + (\tan \theta_{nl} - \tan \theta_{n'l})$$

以上の各記号に於ける n は橋の左側に於ては中央の垂直材より左側にある格間の数の 2 倍を、橋の右側に於ては中央の垂直材より右側にある格間の数の 2 倍を表わす。この例に於ては橋の左側、右側ともに $n=6$ である。

5. むすび

格間数 7 の場合も同様に連立方程式の表を求める事が出来る。任意の格間数の場合に対しては、上のようにして求めた格間数 6, 7 の場合を推し進めれば機械的に連立方程式の表が求まる。

かくして求めた各方程式は荷重、温度変化ともにその影響を考慮したもので、之に依り荷重、温度の両応力を一度に求める事が出来る。之等を別々に解きたい時には、荷重応力に対しては (28) 式の右辺の $6E\epsilon t$ 、及び (29) 式の右辺の $-E\epsilon t \Sigma(\tan \theta_{rl} - \tan \theta_{r'l})$ を除き、温度応力に対しては右辺の $\alpha_r, \beta_r, \gamma_r, \delta_r, \epsilon_r, \zeta_r, \eta, \nu, \xi, \rho$ を除き且つ $\Sigma P=0, [A]=-[H] \tan \alpha$ (α は支点 1, 1' を結ぶ線の水平となす角度) とおき (29) 式を省略すれば良い。

上弦材水平な場合は、各方程式に於て $\theta_{ru}=0$ とおけば良く、又 2 ヒンジアーチ橋の場合は $M_1=0, M_1'=0$ とおき、 Φ_1, Φ_1' を未知数とし、垂直反力 A を既知数とすれば良い。

フィレンデルトラス橋の場合は $M_1=0, M_1'=0, H=0$ とおき、 Φ, Φ_1' を未知数とし、垂直反力 A を既知数とすれば良い。尚下弦材水平、上弦材曲弦のフィレンデルトラス橋の場合は更に $\theta_{rl}=0$ とおけば良く、上下弦材共水平な所謂平行弦フィレンデルトラス橋の場合は $\theta_{rl}=0, \theta_{ru}=0$ とおけば良い。即ちフィレンデル固定アーチ橋に対する表-1 の形の連立方程式よりあらゆる型のフィレンデル型橋梁の応力を求めるための連立方程式が誘導出来る。

尙本解法に依ればリブアーチ橋に於て、床版、支柱或いは床版、吊材がリブの応力に及ぼす影響を明らかにする事が出来る。

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