琉球大学学術リポジトリ

不完全合成桁の挙動に関する研究

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第8章　結　　語

不完全合成桁、断続合成桁および曲線合成桁の力学的挙動に関する基礎的諸問題について理論的および実験的に検討を行い、合成桁の設計上の基礎的資料を求めた。本論文の各章の内容については第1章で概説し、得られた結論については各章末で述べたが、それをまとめると以下のようである。

第1章では合成構造の諸問題について述べるとともに、不完全合成桁、断続合成桁および曲線合成桁に関する既往の研究の展望を行い、本論文の内容と構成について述べた。

第2章はコンクリートスラブと鋼桁の接合面にずれの生じる不完全合成桁の新しい有限要素解析モデルを示し、その要素を用いたひび割れを考慮した連続合成桁の解析法およびコンクリート、鋼材およびずれ止めの各材料非線形を考慮した解析法について述べた。ここで示した新しい合成桁モデルとは、コンクリートスラブと鋼桁を軸力と曲げを受けるはり要素で、ずれ止めは接合面に作用する水平せん断力のみに抵抗するばね要素でモデル化したものである。なお、コンクリートスラブ要素と鋼桁要素の橋軸方向変位は、要素内において複雑に変化する軸力をより正確に表現するために三次式で仮定し解析を行った。連続合成桁の解析では、負の曲げモーメント区間におけるコンクリートスラブのひび割れの影響を等価な力に置き換え反復計算により解析を行った。また、合成桁の弾塑性解析では、コンクリートおよび鋼材の応力—ひずみ関係およびずれ止めの力—ずれ関係を簡単な仮定で表し、それらの影響を初期ひずみの項として取り扱い反復初期ひずみ法により計算を行った。また、本解析結果と他で行われた実験結果および数値解析結果との比較検討を行うことにより、本章で示した解析法は、連続合成桁の解析および合成桁の材料非線形問題の解析に有効な解析法であることを示した。

第3章では不完全合成桁の接合面のずれを考慮した有効幅を定義し、単純T形ばり、無限並列ばり、張り出し部がないπ形ばり（対称および逆対称荷重）に等分布荷重および集中荷重が作用した場合について応力関数を用いた解式を誘導し、それぞれの場合の支間中央点の有効幅比を示した。得られた主な結論は次のとおりである。

1)　不完全合成桁では、コンクリートスラブと鋼桁の間に配置されたずれ止めの変形によるずれが生じ、コンクリートスラブに作用する力が緩和され、コンクリートスラブに作用する応力が減少することが知られているが、接合面のずれは不完全合成桁の有効幅に大きな影響を与える。

2)　ここで示した有効幅には、不完全合成桁を構成する材料の特性、桁の形状とコンクリートスラブと鋼桁の断面比の影響が含まれているが、断面の諸因子の有効幅に及ぼす影響は、等分布荷重が載荷された場合は小さく、集中荷重が載荷された場合は多少大きい。

3)　ここで提案した有効幅を用い初等ばり理論によって計算された応力と道路橋示方書の規定有効幅を用いて計算した応力を比較すると、道路橋示方書の規定有効幅による応力の方が鋼桁下フランジで多少大きく、上フランジでかなり小さい。

第4章では負の曲げを受ける区間にずれ止めを配置しない断続合成桁の負の曲げを受ける区間の静的および疲労性状について述べた。断続合成桁およびずれ止めを連続的に配置した合成桁について負の曲げのみを受ける実験モデルを作製し静的および疲労試験を行い、荷重変形性状、ずれ性状、橋軸方向鉄筋の応力分布、ひび割れ性状および曲げ耐荷力について調べた。得られた主な結論は次のとおりである。

1) 荷重とたわみの関係より、ずれ止めを連続的に配置した桁と断続合成桁の桁の剛性を比較すると、断続合成桁の方が桁剛性は低い。一方、荷重とたわみの関係は繰返し回数の増加とともに理論値に近くなる。また、繰返し回数の増大とともに残留たわみがひび割れの増加とともに大きくなる。

2) 橋軸方向鉄筋は、断続合成桁においても有効に作用している。ＡＡＳＨＴＯの示方書では橋軸方向鉄筋は応力計算において無視しているが、鉄筋は有効に作用しており応力計算に含めても差し支えないものと考えられる。

3) 荷重とひび割れ幅は比例的関係にある。設計荷重載荷時の最大ひび割れ幅は繰返し回数が増大してもほぼ一定であり、ずれ止めの配置法の違いによる顕著な差は見られない。また、道路橋示方書のプレストレスしない連続合成桁に規定されている鉄筋量（コンクリートスラブ断面積の２％、周長率0.045cm/cm^{2}以上）を用いると設計荷重載荷時の最大ひび割れ幅は0.2mm以下であった。

4) 終局耐力は、断続合成桁において横倒れ座屈が生じないならば、断続合成桁とずれ止めを連続的に配置した桁では差はほとんど見られなかった。また、繰返し載荷による耐力の低下は見られない。

第5章では断続合成桁の断続部分のたわみおよび応力に関する計算法について述べた。本計算法で断続合成桁の挙動を調べた結果得られた主な結論は次のようである。

1) 断続合成桁のコンクリートスラブ重心軸に作用する応力は、剛なずれ止めを連続的に配置した完全合成桁の最大値の1/2となる。

2) 断続合成桁ではスラブの応力が低下する割には鋼桁下フランジの応力はあまり増加しない。

3) 負の曲げを受ける区間の一部を合成した部分断続合成桁は、負の曲げを受ける区間全域を非合成とした断続合成桁と比較すると桁の剛性が増加し、他方、スラブの応力はそれほど増加せず有効な構造系である。

第6章では不完全曲線合成桁の有限帯板法による三次元的解析のための定式化について述べた。本解析法では、コンクリートスラブと鋼桁をそれぞれ曲線帯板要素で、接合面に配置されたずれ止めを橋軸および半径方向の二次元のばね要素でモデル化し解析を行った。本解析法は、有限帯板法を用いているため、断面内のみで要素分割を行えばよく、また、つり合い方程式は級数の各項で独立しており、少ない未知数で曲線合成桁の三次元的解析を行うことができる。また、ずれ止めは橋軸方向にわたって一定の剛性を持つものと仮定するが、断面内では種々のずれ止めの配置が可能であり、曲線合成桁の挙動解析に適していると考えられる。

第7章では箱桁断面を有する曲線合成桁の弾性挙動について述べた。箱桁断面を有し単純支持された曲線合成桁３体について静的載荷試験を行い、さらに、第６章で示した有限帯板法による解析法を用い実験モデルについて数値解析を行い、実験結果と解析結果を比較検討しながら箱桁断面を有する曲線合

成桁の弾性挙動について考察を加えてある。得られた主な結論は次のようである。

1) 曲線合成桁の内側部分に偏心載荷を行うと大きな断面変形が生じ、それにより桁の内側部分に大きな橋軸方向応力が生じる。その影響は曲率半径が小さい場合に顕著に現れる。なお、曲線合成桁の外側部分に偏心載荷を行った場合はその影響は小さい。

2) 曲線合成桁の内側部分に偏心載荷を行った場合、桁の中央部では内側ウェブでせん断力を多く受け持ち、桁端部に近づくに従って外側ウェブでも分担するようになるが、外側部分に偏心載荷を行った場合は桁全長にわたって外側ウェブのみでせん断力を分担する傾向がある。

3) 橋軸方向にずれ止めに作用する力は、せん断応力と同様な分布性状を示した。鋼桁が開断面を有する曲線合成桁のウェブ上のみにずれ止めを配置した場合、外側ウェブ上のずれ止めに作用する力は内側ウェブ上のそれと比較すると大きく、その傾向は曲率半径が小さくなると顕著に現れる。設計においては十分なる配慮が必要である。一方、鋼桁が閉断面を有する曲線合成桁の鋼桁上フランジにずれ止めを配置した場合、ずれ止めは有効に作用している。

4) 曲線合成桁の桁端部において、ずれ止めの半径方向に大きな力が作用するおそれがあり、ずれ止めの配置法において十分注意する必要がある。

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記　　　号

A ：断面積

A_c ：コンクリートスラブの断面積

A_i^r ：鉄筋の断面積

A_s ：鋼桁の断面積

A_m, B_m, C_m, D_m ：積分定数

a ：コンクリートスラブ要素の軸ひずみの付号が変化する点までの距離

a_c, a_c ：完全合成桁の重心軸からコンクリートスラブおよび鋼桁断面のそれぞれの重心軸までの距離

B, b ：コンクリートスラブの幅あるいは要素幅

C_s, C_c ：鋼桁およびコンクリートスラブ重心軸から接合面までの距離

$[D]$ ：弾性マトリックス

d_i ：鉄筋コンクリート要素の重心軸から鉄筋が配筋されている箇所までの距離

d^u, d^ℓ ：はり要素上面から弾塑性境界面までの距離

E ：弾性係数

E_c ：コンクリートの弾性係数

E_s ：鋼材の弾性係数

e ：反復計算における誤差

F ：ずれ止めに作用する力

F_c ：完全合成桁のずれ止め一本当たりに作用する力

F_p ：断続合成桁のずれ止め一本当たりに作用する力

F_u ：ずれ止めの破壊荷重

F_y ：ずれ止めの弾性限の力

F_θ, F_r ：曲線合成桁のずれ止めに作用する橋軸および半径方向の力

$F(x,y)$ ：Airy の応力関数

G ：せん断弾性係数

G_c ：コンクリートのせん断弾性係数

G_s ：鋼材のせん断弾性係数

$g_1 \sim g_4$ ：形状関数

$h(z)$ ：コンクリートスラブ要素におけるひび割れの深さ

I ：断面二次モーメント

I_c ：コンクリートスラブの断面二次モーメント
I_s ：鋼桁の断面二次モーメント
I_w ：そりねじり定数
K ：純ねじり定数
K_1, K_2, K_3 ：コンクリートスラブと鋼桁の断面比およびずれ止めの剛性を表わすパラメーター
$[K]$ ：剛性マトリックス
$[K_b]$ ：はり要素の剛性マトリックス
$[K_b^*]$ ：はり要素の塑性による初期ひずみマトリックス
$[K_c]_{prism}$ ：コンクリートスラブ（Finite Prism）要素の剛性マトリックス
$[K_{crack}^1], [K_{crack}^2]$ ：コンクリートスラブ要素のひび割れによる初期ひずみマトリックス
$[K_r]$ ：鉄筋要素の剛性マトリックス
$[K_r^*]$ ：鉄筋要素の塑性による初期ひずみマトリックス
$[K_s]$ ：曲線帯板要素の剛性マトリックス
$[K_s]_{strip}$ ：鋼桁（Finite Strip）要素の剛性マトリックス
$[K_{sc}]$ ：ずれ止め要素の剛性マトリックス
$[K_{sc}^*]$ ：ずれ止め要素の塑性による初期ひずみマトリックス
k ：第3章では $k=m\pi/L$
第6章では $k=m\pi/\alpha$
第7章ではねじり定数比 $k=\ell\sqrt{GK/EI_w}$
k_θ, k_r ：曲線合成桁における橋軸および半径方向のずれ止めの剛性
L, ℓ ：スパンあるいは要素長
第4章では圧縮フランジの固定点間距離
$M, M(x)$ ：曲げモーメント
M_m ：曲げモーメントをFourier級数で展開した場合のFourier係数
m ：項数
m_c ：完全合成桁の一列に配置されたずれ止めの本数
m_p ：断続合成桁の断続点に配置されたずれ止めの本数
N ：曲線合成桁の断面内におけるずれ止めの配列の個数
N_n ：アイソパラメトリック要素における形状関数
n ：コンクリートと鋼材の弾性係数比
第2章では鉄筋の本数
P_u ：極限荷重
$\{P\}$ ：荷重ベクトル

$\{P\}^{i-1}$ ：修正荷重項

$\{P\}_m$ ：第m項の荷重項

$Q, O_1, Q_2, q_s, q_1, q_2$ ：ずれ止めの剛性

Q_p ：断続合成桁の接合面に作用する水平せん断力

q_c ：完全合成桁の接合面の単位長さ当たりに作用する水平せん断力

R, r ：曲率半径

$[R]$ ：座標変換マトリックス

s ：ずれ止めの橋軸方向の配置間隔

t ：コンクリートスラブの厚さあるいは要素の厚さ

u, v, w ：X、Y、Z方向の変位

$u_{im}, v_{im}, w_{im}, \varphi_{im}$ ：i節点における変位パラメーター

$\{u\}$ ：変位ベクトル

$\{u\}_m$ ：変位パラメーターベクトル

X ：外力ベクトル

$\bar{y}$ ：コンクリートスラブおよび鋼桁要素の重心軸間の距離

y_u, y_ℓ ：鋼桁重心軸から上下フランジまでの距離

z_s, z_c ：曲線合成桁の鋼桁上フランジおよびコンクリートスラブの重心軸から接合面までの距離

α ：曲線合成桁の中心角

β ：第２章ではz/ℓ
第３章ではy/B
第６章ではx/b

γ ：コンクリートスラブと鋼桁の断面積比

$\Delta_s, \Delta_r, \Delta_\theta$ ：コンクリートスラブと鋼桁の接合面のずれ

Δ_s^e ：弾性成分のずれ

Δ_s^p ：塑性成分のずれ

$\{\Delta_s^p\}$ ：ずれ止め要素の塑性ずれベクトル

δU ：内部仮想仕事

δU_b ：はり要素の内部仮想仕事

δU_c ：コンクリートスラブ要素の内部仮想仕事

δU_c^* ：コンクリートスラブ要素のひび割れ発生による低減内部仮想仕事

δU_{curve} ：曲線帯板要素の内部仮想仕事

δU_r ：鉄筋要素の内部仮想仕事

δU_s ：鋼桁要素の内部仮想仕事

δU_{sc} ：ずれ止め要素の内部仮想仕事
ε ：ひずみ
ε_{ij} ：ひずみテンソル
ε_{p}^{u}, ε_{p}^{ℓ} ：はり要素上下塑性領域内の塑性ひずみ
ε_{z}^{e} ：弾性成分のひずみ
ε_{z}^{p} ：塑性成分のひずみ
ε_{z}^{T} ：全ひずみ
$\{\varepsilon\}$ ：ひずみベクトル
$\{\varepsilon_{p}\}$ ：はり要素の塑性ひずみベクトル
$\{\varepsilon_{p}^{r}\}$ ：鉄筋要素の塑性ひずみベクトル
θ ：帯板要素の橋軸方向回りの回転角
λ ：有効幅
μ ：コンクリートスラブと鋼桁の断面二次モーメント比
ν，ν_{s}, ν_{c} ：ポアソン比
σ，σ_{z} ：応力
σ_{cu} ：コンクリートの圧縮強度
σ_{ct} ：コンクリートの引張り強さ
σ_{design} ：鋼材の許容応力
σ_{ij} ：応力テンソル
(σ_{x}) ：コンクリートスラブに分布する橋軸方向応力
$(\sigma_{x})_{slab}$ ：接合面位置におけるコンクリートスラブの橋軸方向応力
$(\sigma_{x})_{girder}$ ：接合面位置における鋼桁上面のひずみをコンクリートスラブの応力に換算した値
σ_{y} ：鋼材の降伏応力
$\{\sigma\}$ ：応力ベクトル
ϕ ：曲線帯板要素の傾き角
ψ ：第５章では曲率
第６章では曲線帯板要素の橋軸方向回りの回転角

APPENDIX

BIBLIOGRAPHY ON COMPOSITE STEEL—CONCRETE CONSTRUCTION

はじめに

合成構造に関する本文献目録は、著者が収集した文献データをもとに作成されている。文献目録はAuthor List、Key Word ListおよびSource Listから構成されている。

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