

장대레일 축력해석

2002. 10. 19

삼성물산 건설부문 강 동 옥
전주대 객원교수 정 근 영

발표 순서

- 장대레일 일반 사항
- 프로그램(TAP4N) 개요
- 적용 사례(Project)
- 기타 해석
- 부록(사용 요소, 프로그램 검증)

장대레일 일반 사항

● 정의

정척레일을 연속 용접하여 1개의 레일길이를
200m 이상으로 부설한 레일

● 장대레일화

- 차량 시동/제동하중에 의한 교축방향 수평력 작용
- 기존 : 수평력 배분을 위해 단순교로 시공(레일 이음매)
- 현재 : 장대레일화

● 장점

유지보수비 절감
승차감 향상(충격/소음 저감)
고속화 및 운행 안전성 향상

● 단점

큰 레일 축력(파단/좌굴)
교량부, 급곡선부, 분기부
장대레일 종하중(하부구조)



프로그램(TAP4N) 개요

1. 장대레일 문제 해석 프로그램

Track Analysis Program For Non-Linear Dynamic Problems

2. 특징

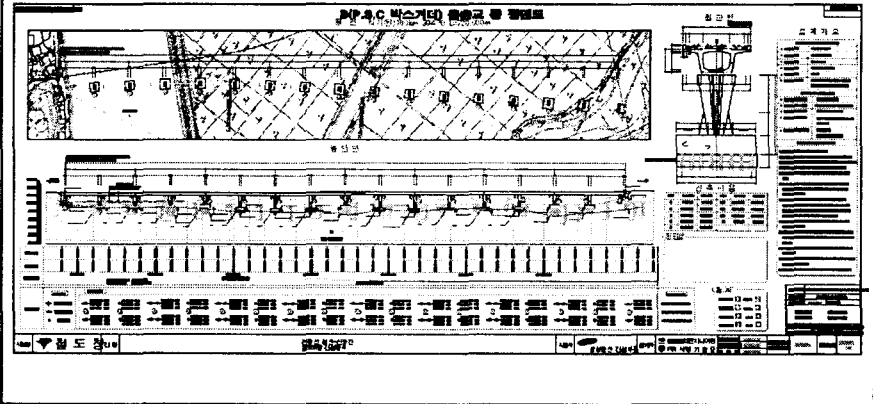
- Nonlinear Newmark Time Integration
- BEAM, FJOINT & WJOINT Elements
- Material Nonlinear for FJOINT & WJOINT
- Updated Lagrangian Formulation
- Load Definition Using Time Function
- Rayleigh Damping
- Eigenvalue Analysis
- Linear Buckling Analysis
- Multi-step analysis



해석 대상 교량

전라선 을촌교

- PSC 박스거더교
- 곡선교



모델링

1. 슈 특성값

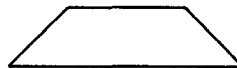
- 기본설계
- 고정단, 이동단으로 모델링

2. 도상 저항력

- 12 KN/m for ballast per track

3. 레일 특성값

- 60KG 표준레일 특성값
- 가동구간 길이 산정(150m 사용, 해석상 50m로 충분) : 경계조건 설정



도상저항력 $r_0 = 12 \text{ kN/m}$ for ballast per track, 온도 $\Delta T = 40^\circ\text{C}$,

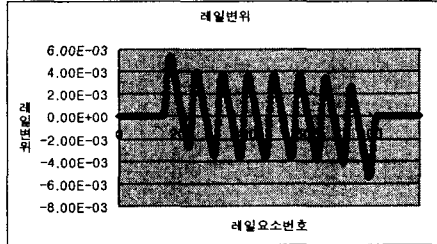
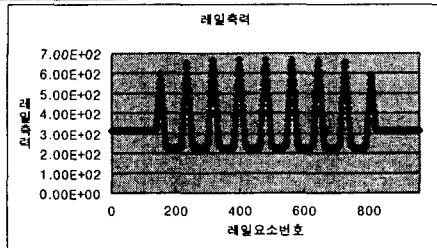
$$E = 2.1 \times 10^7 \text{ t/m}^2, A = 0.0155 \text{ m}^2, \alpha = 1.2 \times 10^{-5}$$

(산정식) $L = P / r_0 = (EA\alpha\Delta T) / r_0 = 130.2 \text{ m}$

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삼성건설

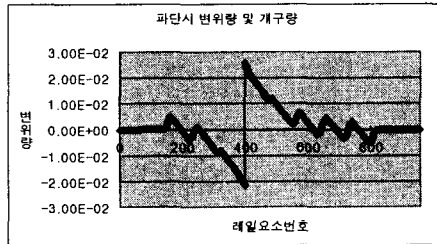
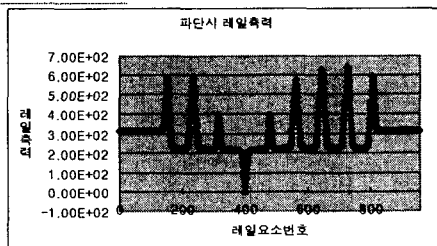
축력해석(-40℃:인장력)



- * 온도 : rail -40℃
교량 -25℃
- * 최대 인장력
- 발생위치
: 교량 상부구조의
이동단 위치
- 크기 : 665 tf

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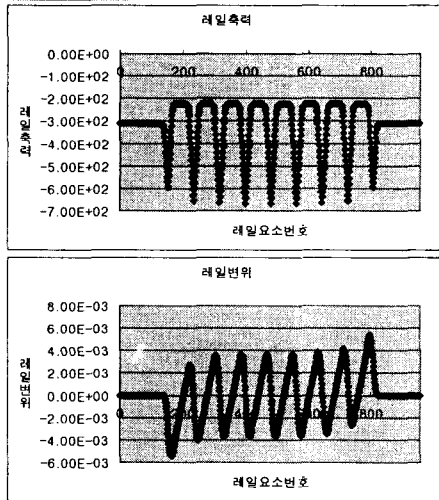
축력해석(-40℃:파단시 개구량)



- * 다단계 해석
최대인장력 절점
보요소강성 ∞ 0
- * 파단시 개구량
: 4.76 cm
- * 수계산
 $D = 2\delta$
 $= EA(\alpha \Delta T)^2 / r_0$
 $= P_{max}^2 / EA r_0$

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축력해석(+40℃:압축력)

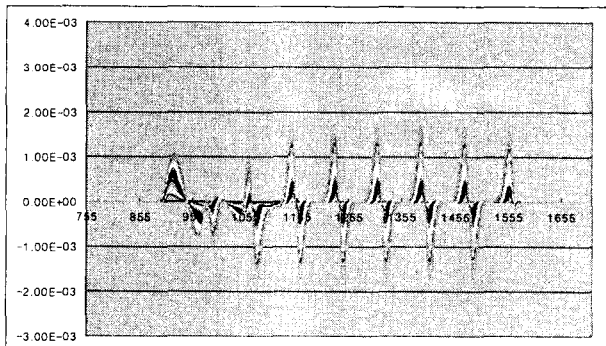


- * 온도 : rail 40℃
교량 25℃
- * 최대 인장력
 - 발생위치 : 교량 상부구조의 이동단 위치
 - 크기 : 665 tf

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축력해석(좌굴해석)

- 교량 곡선부에 대해 해석 수행
- 온도를 160℃까지 증가시키면서 해석
- 좌굴 발생하지 않음.(궤도를림 정비기준 2mm)

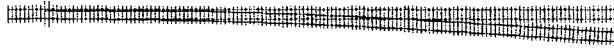


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삼성건설

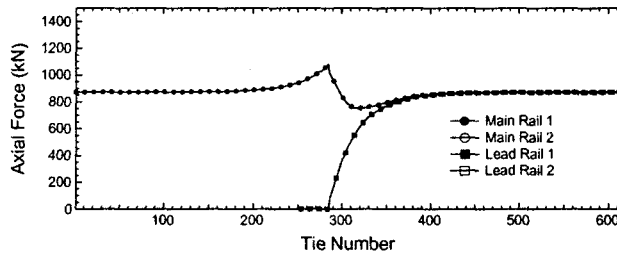
분기부 해석

• Turnout Model #18.5

- Geometry



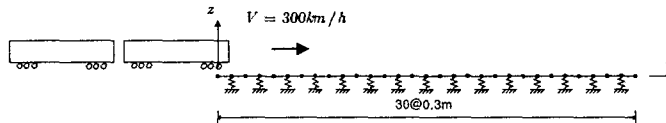
- Analysis Results



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삼성건설

이동하중에 의한 동적해석

• 해석모델



$$\text{Two } 60\text{kg rails: } E = 2.1 \times 10^7 \text{ t/m}^2, \nu = 0.3, \rho = 7.8452 \text{ t/m}^3, A = 0.0155 \text{ m}^2,$$

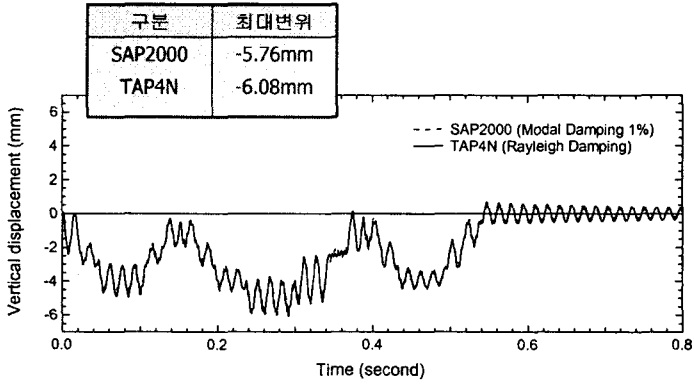
$$I_y = 0.006184 \text{ m}^4, I_z = 0.009004 \text{ m}^4, J = 0.007204 \text{ m}^4$$

$$\text{Ground spring: } k = 1.2 \times 10^3 \text{ t/m}$$

Modal damping: 1% Modal damping

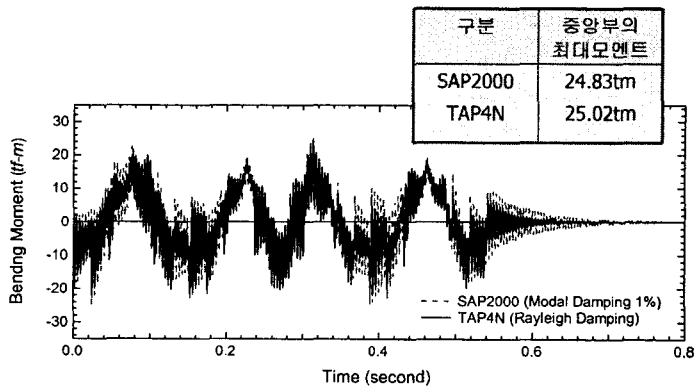
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이동하중에 의한 동적해석



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이동하중에 의한 동적해석

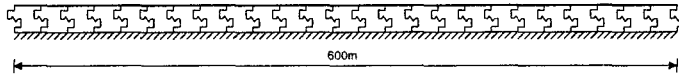


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온도증감에 따른 궤도축력변화

● 해석모델

Temperature change in a single track (two rails)



Two 60kg rails : $E = 2.1 \times 10^7 t/m^2$, $\nu = 0.3$, $\rho = 7.8452t/m^3$, $A = 0.0155m^2$,
 $I_y = 0.006184m^4$, $I_z = 0.009064m^4$, $J = 0.007204m^4$
 $\alpha = 1.2 \times 10^{-5} \text{ } ^\circ C^{-1}$

Longitudinal Resistance : $r_o = 1.2t/m$ for ballast

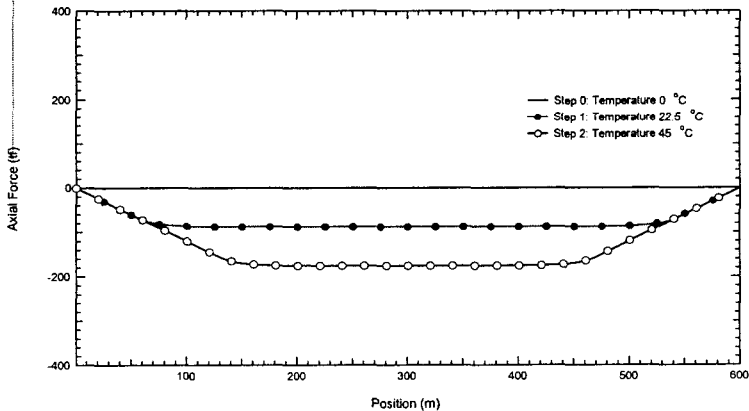
$C = r_o / (u_{pl} \times width) = r_o / (0.001m \times 1m) = 1.2 \times 10^3 t/m^3$
 $\sigma_{31}^{yld} = C \cdot u_{pl} = 1.2t/m^2$

Temperature change ΔT : $0^\circ C \rightarrow 22.5^\circ C \rightarrow 45^\circ C \rightarrow 22.5^\circ C \rightarrow 0^\circ C \rightarrow -22.5^\circ C$
 $\rightarrow -45^\circ C \rightarrow -22.5^\circ C \rightarrow 0^\circ C \rightarrow 22.5^\circ C \rightarrow 45^\circ C$



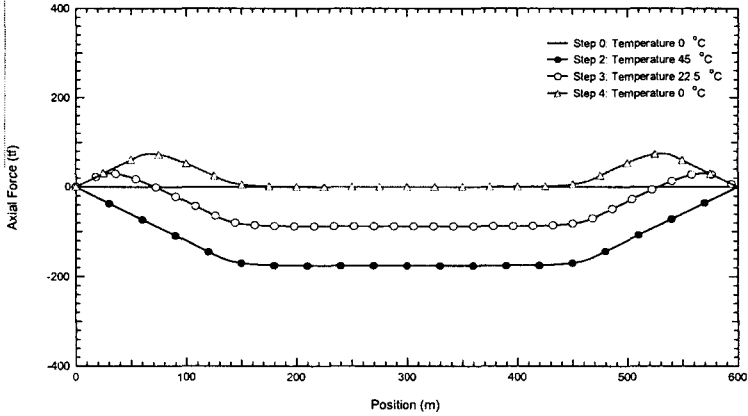
온도증감에 따른 궤도축력변화(계속)

● 장대레일부설후 온도45도 증가



온도증감에 따른 궤도축력변화(계속)

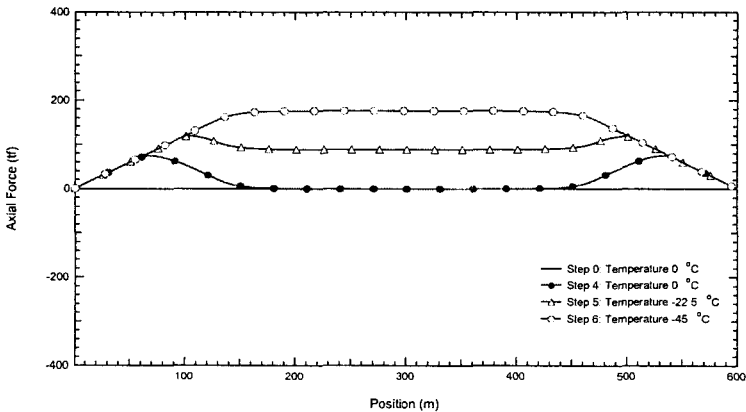
● 45도에서 0도로 온도감소



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온도증감에 따른 궤도축력변화(계속)

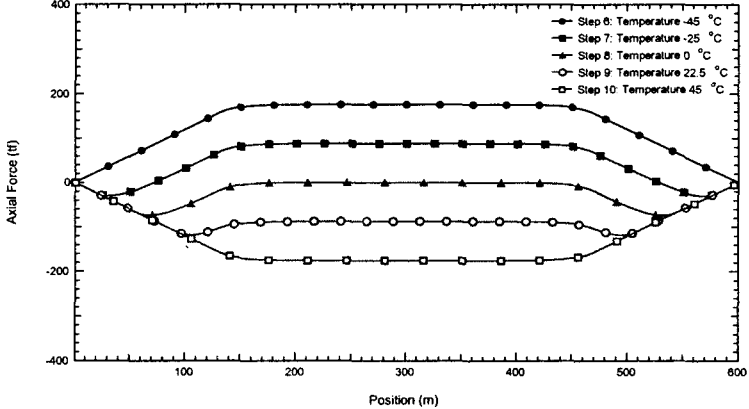
● 0도에서 -45도로 온도감소



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온도증감에 따른 궤도축력변화(계속)

• -45도에서 45도로 온도증가



부록

- 사용 요소
- 프로그램 검증

프로그램 요소

• BEAM Element Formulation

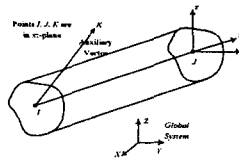
- 3D Beam based on Euler Beam Theory

6 DOF per Node

- Geometric Non-linearity Consideration based on Incremental UL Method

$$M^{t+\Delta t} \ddot{U} + C^{t+\Delta t} \dot{U} + ({}^t K_L + {}^t K_{NL}) U = {}^{t+\Delta t} R - {}^t F$$

- Current Configuration Update
 1. Origin & Direction of local coordinate
 2. The length of element

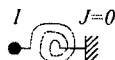
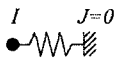
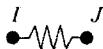
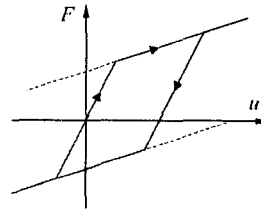


프로그램 요소

• FJOINT Element Formulation

- Nonlinear Flexible Joint Element

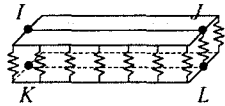
- Assembly of 6 Nonlinear springs for Translation & Rotation



프로그램 요소

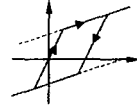
• WJOINT Element Formulation

- Nonlinear Winkler Joint Element



Distributed Springs
in 3 Directions

If $K=L=0$, then attached
to ground



- Winkler Hypothesis

$$\sigma(x) = Cw(x) = C(w_{upper}^h(x) - w_{lower}^h(x))$$

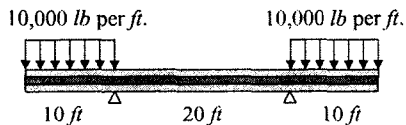
\uparrow \uparrow \uparrow
 F/L^2 F/L^3 L



프로그램의 검증

• Beam Stress & Deflection

- Problem Definition (Ref. SAP6 Problem Verification Manual)



$$A = 50.65 \text{ in}^2$$

$$E = 30 \times 10^6 \text{ psi}$$

$$I = 7892 \text{ in}^4$$

- Analysis Results

1. 중앙점의 연직처짐 : 0.182417 in
2. 중앙점의 휨모멘트 : -60×10^5 in-lb

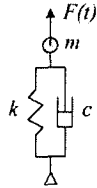
이론값과 일치함



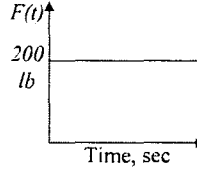
프로그램의 검증(계속)

• Transient Response to a Step Excitation

- Problem Definition (Ref. SAP6 Problem Verification Manual)



$m = 0.5 \text{ lb-sec}^2/\text{in}$
 $k = 200 \text{ lb/in}$
 Time step size = 0.0025 sec
 $\beta = 1/4, \gamma = 1/2$
 $\xi = 0$

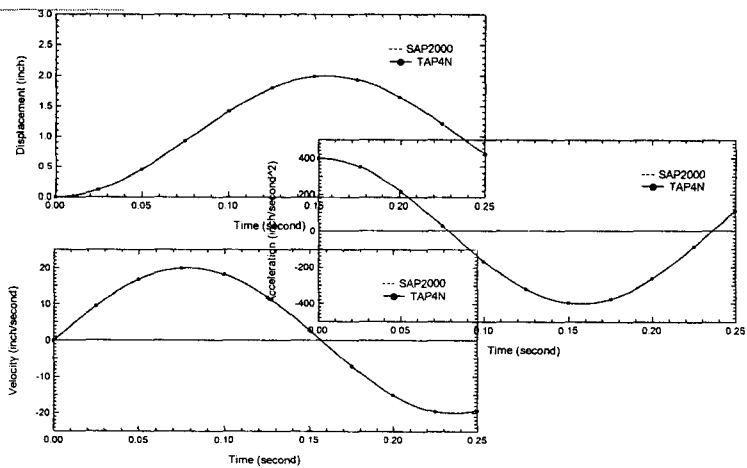


- Analysis Results

구분	U(0.155sec)
Theory	2.000
SAP6	1.999
SAP2000	1.998
TAP4N	1.999

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프로그램의 검증(계속)

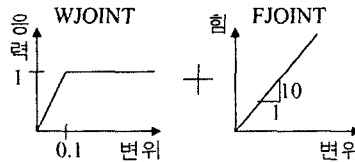
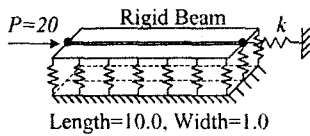


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프로그램의 검증(계속)

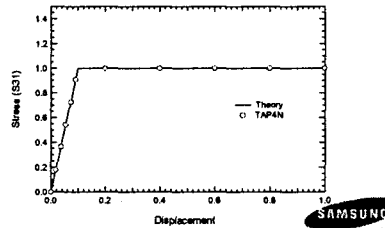
• Nonlinear Behavior of WJOINT

- Problem Definition



- Analysis Result

구분	U
Theory	1.000
TAP4N	1.000



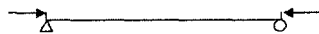
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프로그램의 검증(계속)

• Column Under Eccentric Axial Force

- Problem Definition

10개의 보요소 분할

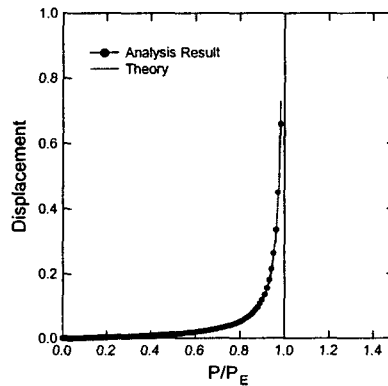


$$E=100.0 \quad L=10$$

$$I=1.0 \quad e=0.01$$

- Theory & Analysis Results

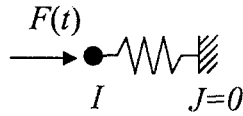
$$\delta = e \left[\sec\left(\frac{\pi}{2} \sqrt{P/P_E}\right) - 1 \right]$$



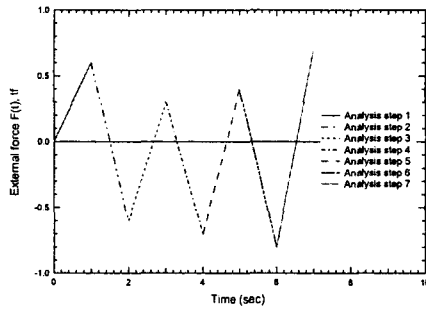
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비선형문제의 단계별 해석

• 해석모델



Initial Spring Stiffness 5 tf/cm
 Yielding Stiffness 1 tf/cm
 Yielding Force 0.5 tf



비선형문제의 단계별 해석(계속)

• FJOINT의 비선형거동

