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某双塔斜拉桥塑性极限有限元模拟分析

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摘要:结合双塔单索面预应力混凝土斜拉桥的结构特点和荷载情况,利用有限元软件ANSYS建立全桥有限元模型,给出了有限元仿真模型命令流;采用非线性静态增量有限元分析,得到了荷载-位移曲线,进而求得了该桥的极限承载力。模拟结果能为实际双塔单索面PC斜拉桥的塑性极限分析提供参考价值。

关键词:双塔单索面预应力混凝土斜拉桥;极限承载力;塑性极限分析;ANSYS

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斜拉桥(cable stayed bridge)主要由索塔、主梁、斜拉索组成,桥面通过多根与索塔连接的斜拉索吊起,属于高次超静定柔性拉索体系[1]。其跨越能力比梁式桥大很多,当桥梁的跨度很大时,普遍采用该桥型。索塔型式有A型、倒Y型、H型、独柱,主要材料为混凝土或钢;斜拉索布置有单索面、平行双索面、斜索面等。世界上第一座现代斜拉桥是瑞典的斯特伦松德(Stromsund)桥,由德国DEMAG公司建于1955年,其主跨为182.6 m。迄今为止,我国已建成和正在施工的斜拉桥达30余座,仅低于德国和日本。2008年6月30日正式通车的苏通大桥,是目前世界上跨径最大、基础最深、桥塔最高及拉索最长的斜拉桥[2-6]。本文结合国内已使用20多年的某座双塔单索面斜拉桥的结构情况和受力特点,采用大型通用有限元软件ANSYS建立全桥有限元模型,通过非线性静态增量有限元分析,得出其荷载-位移曲线,进而求出该桥的极限承载力,希望计算过程及模拟结果为实际双塔单索面预应力混凝土斜拉桥(PC斜拉桥)塑性极限分析提供参考价值。

1 全桥概况及材料参数

该桥为国内某双塔单索面斜拉桥,已经使用20多年,全长共3 616.70 m,主要组成部分为主桥、引桥、匝道等,总体布置见图1。主桥由跨径为105 m+210 m+105 m双塔单索面PC斜拉桥和两侧分别为9 m×50 m×和3 m×50 m的连续梁构成,本文只考虑PC斜拉桥的部分。假设斜拉桥两端和连续梁为铰接连接,塔、墩、梁固结;主梁采用3室闭合箱梁,梁高3.4 m,箱梁底宽15 m,上缘用4.9 m长的悬臂挑出,总宽度30.1 m,路面净宽25 m,截面如图2所示;塔为倒Y型独柱结构,桥面以上塔柱总高为54 m,其中锚固段为H型截面,高31 m,下部塔腿为矩形截面,高23 m。斜拉索采用扇形布置,材料为我国高强钢丝,表面内防护采用喷涂锌铝合金,每个塔都包含15对拉索,共60根斜拉索,拉索间距6.2 m,从外到内,拉索的倾角为26°~62°。该桥原设计荷载为汽-20、挂-100级,本文参考新规范中的公路Ⅱ级设计荷载,对荷载进行转换,恒载和活载按均布荷载设计。桥各主要材料参数见表1,斜拉索的具体参数见表2。

2 全桥有限元模型的建立

采用大型通用有限元软件ANSYS对该桥梁进行有限元建模分析。假设所有材料都是理想弹塑性,在ANSYS中对模型进行非线性静态增量分析,主塔采用beam54、2节点3自由度渐变梁单

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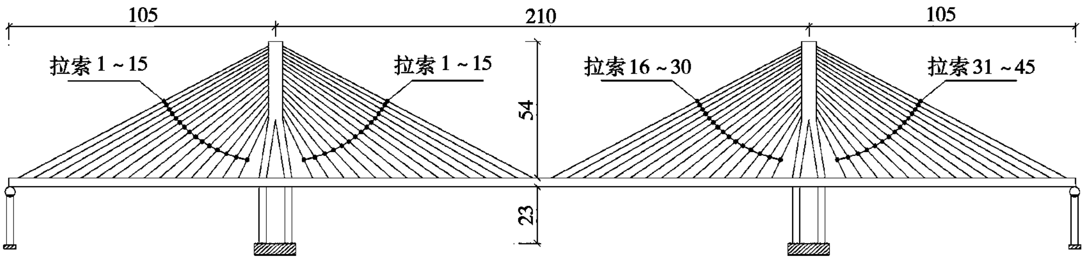

图 1　双塔单索面斜拉桥总体布置图(m)

Fig. 1　General layout of double-pylon single cable plane cable-stayed bridge (m)

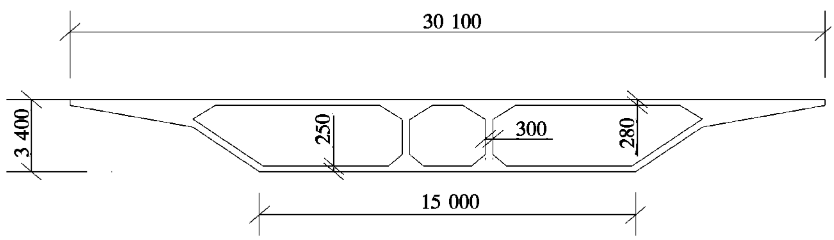

图 2　双塔单索面斜拉桥 3 室箱梁截面图(mm)

Fig. 2　Three box girder section of double-pylon single cable plane cable-stayed bridge(mm)

表 1　某双塔单索面斜拉桥主要材料参数表

Table 1　The main material parameters of a double pylon single plane cable – stayed bridge

结构部位	材料	弹性模量/MPa	剪切模量/MPa	泊松比	截面积/m^2	容重/($kN \cdot m^{-3}$)
主梁	C40	3.25E+04	1.38E+04	0.17	25.8	25
上塔柱	C50	3.45E+04	1.47E+04	0.17	13.08 ~ 16.54	25
下塔柱	C50	3.45E+04	1.47E+04	0.17	9.1	25
拉索	φ7 高强钢丝束	2.05E+05	8.29E+04	0.3	0.0058 ~ 0.0084	78.5

元;主梁采用 Beam188、2 节点 6 自由度梁单元;斜拉索采用 Link10、2 节点 3 自由度杆单元,斜拉索的初拉力通过改变单元的初始应变实现。对于此斜拉索,通常有如下假设:拉索只在其截面上产生均匀分布的法向应力,且在应力的作用下,其截面面积不产生变化。

通过 ANSYS 软件建立斜拉桥的二维模型见图 3,3 室箱梁截面模型见图 4。

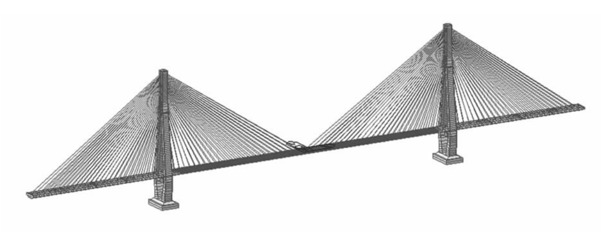

图 3　ANSYS 模型

Fig. 3　ANSYS model

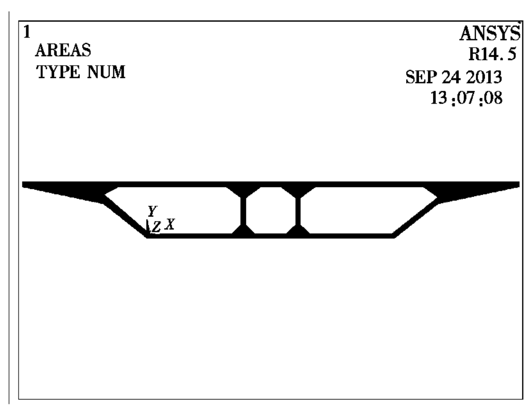

图 4　自定义 3 室箱梁截面

Fig. 4　Customized three box girder section

3　非线性静态增量分析

通过 ANSYS 非线性静态增量分析,得到该斜拉桥的荷载-位移曲线,见图 5。通过荷载位移曲线求得该桥极限荷载约为 1 956 kN。

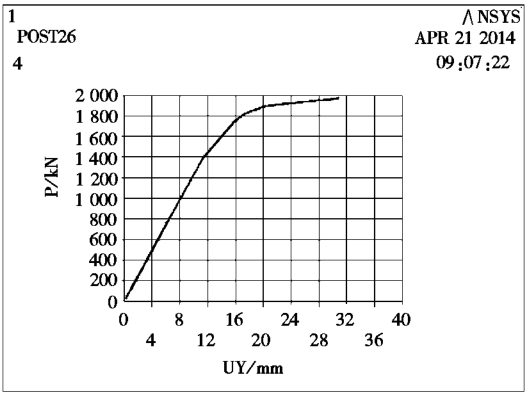

图 5　荷载位移曲线

Fig. 5　The load-displacement curve

4　有限元模拟命令流[7]：

/clear $ /prep7 $ k,1 $ k,2,15 $ k,3,17.65,2.095 $ k,4,22.55,3.12 $ k,5,22.55,3.4 $ k,6,-7.55,3.4 $ k,7,-7.55,3.12 $ k,8,-2.65,2.095 $ a,1,2,3,4,5,6,7,8 $ k,9,0.168,0.25 $ k,10,5.128,0.25 $ k,11,5.694,0.808 $ k,12,5.694,2.455 $ k,13,4.794,3.12 $ k,14,-1.756,3.12 $ k,15,-2.621,2.65 $ a,9,10,11,12,13,14,15 $ k,16,6.561,0.25 $ k,17,8.439,0.25 $ k,18,9.006,0.808 $ k,19,9.006,2.455 $ k,20,8.105,3.12 $ k,21,6.895,3.12 $ k,22,5.994,2.455 $ k,23,5.994,0.808 $ a,16,17,18,19,20,21,22,23 $ k,24,9.872,0.25 $ k,25,14.832,0.25 $ k,26,17.65,2.478 $ k,27,16.756,3.12 $ k,28,10.206,3.12 $ k,29,9.306,2.455 $ k,30,9.306,0.808 $ a,24,25,26,27,28,29,30 $ asba,1,2 $ asba,5,3 $ asba,1,4 $ et,1,plane82 $ lesize,all,,,0.5 $ amesh,all $ secwrite,mybox

finish $ /clear $ /filename,cablestayed bridge,1

/Title, The plastic anlysis of cable-stayed bridge

/replot $ /prep7

et,1,link10 $ et,2,beam189 $ keyopt,2,7,1 $ et,3,beam54！分别定义斜拉索、主梁和主塔的单元类型

mp,ex,1,2.05e11 $ mp,prxy,1,0.3 $ tb,bkin,1 $ tbdata,1,1.67e9,0.0 $ mp,ex,2,3.25e10 $ mp,prxy,2,0.17 $ mp,gxy,2,1.38e10 $ tb,bkin,2 $ tbdata,1,4e7,0.0 $ mp,ex,3,3.45e10 $ mp,prxy,3,0.17 $ mp,gxy,2,1.47e10！定义塑性材料参数

tb,bkin,3 $ tbdata,1,5e7,0.0 $ sectype,1,beam,mesh $ secread,mybox,,,mesh！定义主梁和主塔的截面

sectype,2,beam,i $ secdata,5.28,5.28,4.6,0.6,0.6,2.7

r,1,0.0084,0.003315 $ r,2,0.0084,0.003216 $ r,3,0.0084,0.003114 $ r,4,0.0084,0.003009 $ r,5,0.0081,0.003005 $ r,6,0.0077,0.003035 $ r,7,0.0077,0.002906 $ r,8,0.0072,0.002964 $ r,9,0.0072,0.002816 $ r,10,0.0063,0.003043 $ r,11,0.0063,0.002866 $ r,12,0.0063,0.002688 $ r,13,0.0058,0.002727 $ r,14,0.0058,0.002542 $ r,15,0.0058,0.002371 $ r,16,0.0058,0.002372 $ r,17,0.0058,0.002542 $ r,18,0.0058,0.002727 $ r,19,0.0063,0.002699 $ r,20,0.0063,0.002866 $ r,21,0.0063,0.003043 $ r,22,0.0072,0.002816 $ r,23,0.0072,0.002964 $ r,24,0.0077,0.002906 $ r,25,0.0077,0.003035 $ r,26,0.0081,0.003005 $ r,27,0.0084,0.003008 $ r,28,0.0084,0.003114 $ r,29,0.0084,0.003216 $ r,30,0.0084,0.003314！定义实常数

k,1 $ k,2,5.98 $ k,3,12.18 $ k,4,18.38 $ k,5,25.58 $ k,6,30.78 $ k,7,36.98 $ k,8,43.18 $ k,9,49.38 $ k,10,55.58 $ k,11,61.78 $ k,12,67.98 $ k,13,74.18 $ k,14,80.38 $ k,15,86.58 $ k,16,92.78 $ k,17,105 $ k,18,117.22 $ k,19,123.42 $ k,20,129.62 $ k,21,135.82 $ k,22,142.02 $ k,23,148.22 $ k,24,154.42 $ k,25,160.62 $ k,26,166.82 $ k,27,173.02 $ k,28,179.22 $ k,29,185.42 $ k,30,191.62 $ k,31,197.82 $ k,32,204.02 $ k,33,215.98 $ k,34,222.18 $ k,35,228.38 $ k,36,234.58 $ k,37,240.78 $ k,38,246.98 $ k,39,253.18 $ k,40,259.38 $ k,41,265.58 $ k,42,271.78 $ k,43,277.98 $ k,44,284.18 $ k,45,290.38 $ k,46,296.58 $ k,47,302.78 $ k,48,315 $ k,49,327.22 $ k,50,333.42 $ k,51,339.62 $ k,52,345.82 $ k,53,352.02 $ k,54,358.22 $ k,55,364.42 $ k,56,370.62 $ k,57,376.82 $ k,58,383.02 $ k,59,389.22 $ k,60,395.42 $ k,61,401.62 $ k,62,407.82 $ k,63,414.02 $ k,64,420 $ k,65,105,-1 $ k,66,105,23.1 $ k,67,105,26.88 $ k,68,105,29.61 $ k,69,105,31.83 $ k,70,105,33.75 $ k,71,105,35.49 $ k, 72,105,37.11 $k,73,105,38.65 $k,74,105,40.12 $k,75,105,41.55 $k,76,105,42.94 $k,77,105,44.31 $k,78,105,45.65 $k,79,105,46.97 $k,80,105,48.27 $k,81,315,-1 $k,82,315,23.1 $k,83,315,26.88 $k,84,315,29.61 $k,85,315,31.83 $k,86,315,33.75 $k,87,315,35.49 $k,88,315,37.11 $k,89,315,38.65 $k,90,315,40.12 $k,91,315,41.55 $k,92,315,42.94 $k,93,315,44.31 $k,94,315,45.65 $k,95,315,46.97 $k,96,315,48.27 $k,97,105,54 $k,98,315,54！建立关键点

*Do,i,1,63 $l,i,i+1 $ *enddo！建立主梁线单元 $allsel $latt,2,,2,,,,1！赋予主梁线单元材料属性

$l,65,17 $l,17,66 $ *Do,i,66,79 $l,i,i+1

*enddo！建立主塔线单元

l,80,97 $l,81,48 $l,48,82 $ *Do,i,82,95 $l,i,i+1 $ *enddo $l,96,98 $lsel,s,line,,64,97,1 $latt,3,,3,,,,2！赋予主塔线单元材料属性

l,2,80 $l,3,79 $l,4,78 $l,5,77 $l,6,76 $l,7,75 $l,8,74 $l,9,73 $l,10,72 $l,11,71 $l,12,70 $l,13,69

l,14,68 $l,15,67 $l,16,66 $l,18,66 $l,19,67 $l,20,68 $l,21,69 $l,22,70 $l,23,71 $l,24,72 $l,25,73

l,26,74 $l,27,75 $l,28,76 $l,29,77 $l,30,78 $l,31,79 $l,32,80 $l,33,96 $l,34,95 $l,35,94 $l,36,93

l,37,92 $l,38,91 $l,39,90 $l,40,89 $l,41,88 $l,42,87 $l,43,86 $l,44,85 $l,45,84 $l,46,83 $l,47,82 $l,49,82 $l,50,83 $l,51,84 $l,52,85 $l,53,86 $l,54,87 $l,55,88 $l,56,89 $l,57,90 $l,58,91 $l,59,92 $l,60,93 $l,61,94 $l,62,95 $l,63,96！建立拉索杆单元 $lsel,s,line,,98 $latt,1,1,1 $lsel,s,line,,99 $latt,1,2,1 $lsel,s,line,,100 $latt,1,3,1 $lsel,s,line,,101 $latt,1,4,1 $lsel,s,line,,102 $latt,1,5,1 $lsel,s,line,,103 $latt,1,6,1 $lsel,s,line,,104 $latt,1,7,1 $lsel,s,line,,105 $latt,1,8,1 $lsel,s,line,,106 $latt,1,9,1 $lsel,s,line,,107 $latt,1,10,1 $lsel,s,line,,108 $latt,1,11,1 $lsel,s,line,,109 $latt,1,12,1 $lsel,s,line,,110 $latt,1,13,1 $lsel,s,line,,111 $latt,1,14,1 $lsel,s,line,,112 $latt,1,15,1 $lsel,s,line,,113 $latt,1,16,1 $lsel,s,line,,114 $latt,1,17,1 $lsel,s,line,,115 $latt,1,18,1 $lsel,s,line,,116 $latt,1,19,1 $lsel,s,line,,117 $latt,1,20,1 $lsel,s,line,,118 $latt,1,21,1 $lsel,s,line,,119 $latt,1,22,1 $lsel,s,line,,120 $latt,1,23,1 $lsel,s,line,,121 $latt,1,24,1 $lsel,s,line,,122 $latt,1,25,1 $lsel,s,line,,123 $latt,1,26,1 $lsel,s,line,,124 $latt,1,27,1 $lsel,s,line,,125 $latt,1,28,1 $lsel,s,line,,126 $latt,1,29,1 $lsel,s,line,,127 $latt,1,30,1 $lsel,s,line,,128 $latt,1,1,1 $lsel,s,line,,129 $latt,1,2,1 $lsel,s,line,,130 $latt,1,3,1 $lsel,s,line,,131 $latt,1,4,1 $lsel,s,line,,132 $latt,1,5,1 $lsel,s,line,,133 $latt,1,6,1 $lsel,s,line,,134 $latt,1,7,1 $lsel,s,line,,135 $latt,1,8,1 $lsel,s,line,,136 $latt,1,9,1 $lsel,s,line,,137 $latt,1,10,1 $lsel,s,line,,138 $latt,1,11,1 $lsel,s,line,,139 $latt,1,12,1 $lsel,s,line,,140 $latt,1,13,1 $lsel,s,line,,141 $latt,1,14,1 $lsel,s,line,,142 $latt,1,15,1 $lsel,s,line,,143 $latt,1,16,1 $lsel,s,line,,144 $latt,1,17,1 $lsel,s,line,,145 $latt,1,18,1 $lsel,s,line,,146 $latt,1,19,1 $lsel,s,line,,147 $latt,1,20,1 $lsel,s,line,,148 $latt,1,21,1 $lsel,s,line,,149 $latt,1,22,1 $lsel,s,line,,150 $latt,1,23,1 $lsel,s,line,,151 $latt,1,24,1 $lsel,s,line,,152 $latt,1,25,1 $lsel,s,line,,153 $latt,1,26,1 $lsel,s,line,,154 $latt,1,27,1 $lsel,s,line,,155 $latt,1,28,1 $lsel,s,line,,156 $latt,1,29,1 $lsel,s,line,,157 $latt,1,30,1！赋予拉索线单元材料属性

！施加边界条件、荷载 dk,1,ux,uy $dk,64,ux,uy $dk,65,all $dk,81,all $lsel,s,line,,1,63,1 $sfl,all,pres,-803470！划分网格 $allsel $lesize,all,5 $lmesh,all $finish

/solu $isfile, read, itress, txt,, 1 $isfile, list $outres,all,all $allsel $solve

/post1 ！观察结果 $set, last ！设置最后荷载步

5　结论

采用有限元软件 ANSYS 建立双塔单索面斜拉桥全桥仿真模型,并给出了有限元仿真模型命令

流,在ANSYS中对模型进行非线性静态增量分析,得到了荷载-位移曲线,进而求出了该桥的极限承载力。模拟结果能为实际双塔单索面PC斜拉桥的塑性极限分析提供参考价值。

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Finite Element Simulation Analysis of Plastic Limit of a Double Pylon Single Plane Cable-stayed Bridge

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Abstract: Combined with the structural characteristics and load situation of the double pylon single cable plane prestressed concrete cable - stayed bridge, the finite element model of the whole bridge is established by using the finite element software ANSYS, and the finite element simulation model command flow is given. The load displacement curve is obtained by nonlinear static incremental finite element analysis, and the ultimate bearing capacity of the bridge is further obtained. The simulation results can actually provide reference value for the plastic limit analysis of double pylon single cable plane PC cable - stayed bridge.

Keywords: the double pylon single cable plane prestressed concrete cable-stayed bridge; ultimate bearing capacity; plastic limit analysis; ANSYS

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