Excel VBA programming with Excel to compute the load transverse distribution coefficient of G-M method

Lijun Ma¹, Guowen Che¹
¹Baicheng Normal University, Baicheng, 137000, China

Corresponding author and e-mail: Lijun Ma, mljcjy@bcnu.edu.cn

Abstract. In this paper, by analyzing the calculation principles of load transverse distribution coefficient of G-M method, using office software Excel, the calculation model of a universal worksheet is given, making the computation of load transverse distribution coefficient with G-M method more accurate and swift. The model is very practical, and can offer reference for bridge and highway designers.

1. Introduction
As is well known, during the beam bridge designing of highway bridges, we often need calculate the transverse distribution factors of motor vehicle loading, and the G-M method is at present a common method to determine the beam bridge loading transverse distribution factor of highway bridge [1-3]. But this method is with heavy computing burden, cumbersome process, and is likely to make errors. Such as calculating the screw parameters and the longitudinal and transverse relative bending stiffness ratio of girders, these multifarious calculating work can be finished by functions and calculating function offered by Excel, and it is convenient to do check work and modification, the original method to determine influence coefficient K₀, K₁ is to estimate values on curve diagram, thus, the error is larger, and workload is heavy, one can also calculate K₀,K₁ by taking use of functions offered from Excel, and trivial details are needed [4]. In order to reduce the trivial works, we will use the VBA programming function in Excel to calculate influence coefficient K₀, K₁ and loading transverse distribution, through which is accurate and quick.

2. Principle analysis and programming design of G-M method to calculate loading transverse distribution
When we calculate the influence coefficient K₀,K₁, we will use some relevant geometrical parameters, such as the assimilate single-width bending resistance inertia of girders, the assimilate single-width bending resistance inertia moment of crossgirders, the screw parameters and the longitudinal and transverse relative bending stiffness ratio, etc. these geometrical parameters can be calculated by using Excel worksheet or by hand, we can put results in Excel worksheets, in order to use them in calculating programming influence coefficient K₀, K₁.

2.1. G-M method to calculate influence coefficient K
Affected by loading action, the influence coefficient K is the ratio of w to, w is the total deflection value of an arbitrary point on the analogue orthotropic plate and is the assumed average deflection, then we have:
Affected by load $p(x) = \frac{p_0 \sin \frac{m \pi x}{L}}{w}$, the total deflection value can be calculated by formula:

$$EJ \frac{d^4 w}{dx^4} = p(x)$$

We do integral four times to $x$, and put the boundary conditions into $x=0$ and $x=L$, $wT=0$, $\frac{d^2 w}{dx^2} = 0$, ascertain the integral constant, then we get:

$$w_T = \frac{p_0 L^4}{m^4 \pi^4 EJ_s} \sin \frac{m \pi x}{L}$$

So the average deflection along the plate width is:

$$w = \frac{w_T}{2B} = \frac{p_0 L^4}{2B m^4 \pi^4 EJ_s} \sin \frac{m \pi x}{L}$$

According to partial differential equations and corresponding boundary conditions, we can work out the deflection $w(x,y)$ of arbitrary point under load effect, then on the basis of the relations between the internal force and deflection deformation, determine the bending moment on cross section with unit width of arbitrary point, with regard to the plate with fixed width of $2B$, two opposite sides simply supported, side free, and with unit sine load on crosswise arbitrary position $K$.

$$p(x) = \frac{p_0 \sin \frac{m \pi x}{L}}{w}$$

its deflection surface general formula is:

$$w = \sum_{n=1}^{\infty} \left[ A_n \sinh(m \pi x) \cos(m \beta y) + B_n \cosh(m \pi x) \cos(m \beta y) + \frac{C_m}{b} \cosh(m \pi x) \sin(m \beta y) + \frac{D_m}{b} \sinh(m \pi x) \sin(m \beta y) \right]
\cdot \left[ \cos(m \beta y | y - e |) + \frac{a}{b} \sin(m \beta y | y - e |) \right] \sin \frac{m \pi x}{L}$$

Because deflections are in inverse proportion to $m^4$, and series converges fast, in practical application, taking the first term can ensure the computing precision, that is $m=1$, furthermore, take (4) and (5), put them into (1):

$$K = \frac{2B^2 \pi^6 EJ_s}{p_0 L^4} \sum_{m=1}^{\infty} \left[ A_m \sinh(\gamma \beta) \cos(\delta \beta) + B_m \cosh(\gamma \beta) \cos(\delta \beta) + \frac{C_m}{b} \cosh(\gamma \beta) \sin(\delta \beta) + \frac{D_m}{b} \sinh(\gamma \beta) \sin(\delta \beta) \right]
\cdot \left[ \cos(\delta \beta | \beta - \gamma |) + \frac{a}{b} \sin(\delta \beta | \beta - \gamma |) \right]$$

According to the boundary conditions, we will get:

$$A_m = \frac{C_m}{M} \left( \sinh \phi - \sin \phi \right) \left[ \frac{a}{b} \sin \phi \sin \eta - \sin \phi \cos \eta \right] + \frac{R}{M} \left[ 2 \sin \phi \cos \eta + \frac{a^2 - b^2}{b} \sin \phi \sin \eta \right]$$

$$B_m = \frac{C_m}{N} \left( \sinh \phi - \sin \phi \right) \left[ \frac{a}{b} \sin \phi \sin \eta - \sin \phi \cos \eta \right] + \frac{S}{N} \left[ 2 \sin \phi \cos \eta + \frac{a^2 - b^2}{b} \sin \phi \sin \eta \right]$$

$$C_m = \frac{C_m}{M} \left( \sinh \phi - \sin \phi \right) \left[ \frac{a}{b} \sin \phi \sin \eta + \frac{a}{b} \cos \eta \right] + \frac{R}{M} \left[ 2 \sin \phi \cos \eta + \frac{a^2 - b^2}{b} \sin \phi \sin \eta \right]$$

$$D_m = \frac{C_m}{M} \left( \sinh \phi - \sin \phi \right) \left[ \frac{a}{b} \sin \phi \sin \eta - \sin \phi \cos \eta \right] + \frac{S}{N} \left[ 2 \sin \phi \cos \eta + \frac{a^2 - b^2}{b} \sin \phi \sin \eta \right]$$

Among the above results:
M = (2a² - 2b² + 1)bsh ϕchϕ - (2a² - 2b² - 1)asin ηcos η
N = (2a² - 2b² + 1)bsh ϕchϕ + (2a² - 2b² - 1)asin ηcos η
P = chγcos δϕ(asin η - bcos η) - shγsin δϕ(acos η + bsin η)
Q = shγcos δϕ(asin η - bcos η) - chγsin δϕ(acos η + bsin η)
S = chγcos δϕ(a² sin η + 2abcos η - b² sin η) - chγsin δϕ(a² cos η - 2ab sin η - b² cos η)
R = chγcos δϕ(a² sin η + 2abcos η - b² sin η) - shγsin δϕ(a² cos η - 2ab sin η - b² cos η)

We have quoted the signs below:

β = πy
ω = aπ
a = b = πr

From the above, the value of K changes according to β, ψ, γ and δ, it depends on the position of the deflection point y, loading position e, relative bending stiffness θ in lengthways and breadthways, and screw parameters as well.

In two extreme cases, that is:
When α=0, influence coefficient K is also K0, we have

a = b = 1

When β≥ψ:

K₀ = \frac{2\lambda \pi}{sh^2 2\lambda \pi - sin^2 2\lambda \pi} \{2ch\lambda (\pi - \beta) cos \lambda (\pi - \beta) [ch\lambda (\pi + \Psi) cos \lambda ]

(\pi - \Psi) sh2 \lambda \pi - ch\lambda (\pi - \Psi) cos \lambda (\pi + \Psi) sin2 \lambda \pi ] - (ch\lambda (\pi - \beta)

sin \lambda (\pi - \beta) + sh\lambda (\pi - \beta) cos \lambda (\pi - \beta)] \cdot \{ [sin \lambda (\pi + \Psi) ch\lambda (\pi - \Psi)]

- cos \lambda (\pi + \Psi) sh\lambda (\pi - \Psi) sin2 \lambda \pi + sh2 \lambda \pi \cdot [sh\lambda (\pi + \Psi) cos \lambda (\pi - \Psi)

- ch\lambda (\pi + \Psi) sin \lambda (\pi - \Psi)] \}

When β≤ψ:

K₀ = \frac{2\lambda \pi}{sh^2 2\lambda \pi - sin^2 2\lambda \pi} \{2ch\lambda (\pi + \beta) cos \lambda (\pi + \beta) [ch\lambda (\pi - \Psi) cos \lambda ]

(\pi + \Psi) sh2 \lambda \pi - ch\lambda (\pi + \Psi) cos \lambda (\pi - \Psi) sin2 \lambda \pi ] + [ch\lambda (\pi + \beta)

sin \lambda (\pi + \beta) + sh\lambda (\pi + \beta) cos \lambda (\pi + \beta)] \cdot \{ [sin \lambda (\pi + \Psi) ch\lambda (\pi - \Psi)]

- cos \lambda (\pi + \Psi) sh\lambda (\pi - \Psi) sh2 \lambda \pi + sin 2 \lambda \pi \cdot [sh\lambda (\pi + \Psi) cos \lambda (\pi - \Psi)

- ch\lambda (\pi + \Psi) sin \lambda (\pi - \Psi)] \}

When α=1, influence coefficient K is K1, we have:

\alpha = 1, b=0, ϕ = 0, γ = 0, δ = 0, P = π - β - ψ

K₁ = \frac{\sigma}{2sh^2 \sigma} \{ (ch\sigma + sh\sigma) ch\theta - sh\sigma \cdot \theta psinh \theta - \frac{(ch\sigma + sh\sigma) ch\theta - sh\sigma \cdot \theta psinh \theta + (ch\sigma - sh\sigma) ch\theta - sh\sigma \cdot \theta psinh \theta}{3sh\sigma - \sigma}

- \frac{(2sh\sigma + ch\sigma) sh\theta - sh\sigma \cdot \theta psinh \theta}{3sh\sigma + \sigma}

When α is between 0–1, the formula below can compute the load transverse distribution influence coefficients:

K_a = K₀ + (K₁ - K₀)√α
2.2. Influence coefficient K calculating model and programming with G-M method
According to the analysis and summary by the author, this calculating process can still use Excel to build a general worksheet calculation model, so that it can be reused when the girder’s structure size changes [5]. When the girder’s structure size is given, the parameters $B$, $\theta$, $\lambda = \theta / 20.5$, $\sigma = \pi \theta$ that are used when calculating $K_0$, $K_1$ are constant quantities, while $e$, $\beta = \pi y / B$, $\psi = \pi e / B$, $\rho = \pi \cdot |\beta - \psi|$ are variables, the calculation process is simple, we can use calculating function in Excel, $B$ Matches the width of the board by half, loading position $e$ is multiple of the beam positions $y$ and $B$ , in this way, $B$ can be taken as unit width 1 without changing the results [6-7]. The loading positions of $e$ can take respectively as 1, 0.75, 0.50, 0.25, 0, -0.25, -0.50, -0.75, -1, the girder positions of $y$ can be put into directly, or be determined by each girder width and the piece numbers of girders, the girder position is not the original given data in the calculation worksheet, any girder position can be calculated as needed. The calculation of $K_0$, $K_1$ is relatively complex, can be accomplished by Excel VBA programming.

![Figure 1. K0, K1 worksheet of K0, K1.](image)

The parameters needed in $K_0$, $K_1$ calculating programming can be read from sheet1 and sheet2 worksheets respectively, add $K_0$, $K_1$ calculating command button in worksheet sheet2, the Excel VBA programming is as follow.
In above programming, because of Excel VBA offered no hyperbolic sine and hyperbolic cosine functions, the hyperbolic sine and hyperbolic cosine functions are derived from basic mathematical functions.

3. Calculating model and programming on loading transverse distribution coefficient

3.1. Influence line vertical scale calculating model and programming design

design according to people’s habits, establish the influence line vertical scale calculation worksheet as shown in figure 2, values of $K_0$ and $K_1$ can be read directly from sheet2, then calculate $K_\alpha$ and the influence line vertical scale of each loading position by programming.

![Worksheet for vertical coordinates of influence lines.](image-url)

Figure 2. Worksheet for vertical coordinates of influence lines.
The Excel VBA programming for calculating the influence line vertical scales is as follows:

```
Dim m,n,i,ps,j As Integer
Dim nwcs As Double
Dim k(76) As Double
With Sheets("Sheet2")
    m=286
    n=96
    ps=m+n+2
    nwcs=ps/2
    m=ps-nwcs
    Do While m<n-wcs
        With Cells(m+nwcs)
            .Value=ps
            .Borders(left).Style=xlBorders
            .Borders(right).Style=xlBorders
            .Borders(top).Style=xlBorders
            .Borders(bottom).Style=xlBorders
        End With
    End While
End With
With Sheets("Sheet3")
    m=1
    ps=Cells(5,6)
    Do While m<n
        With Cells(m+nwcs)
            .Value=ps
            .Borders(left).Style=xlBorders
            .Borders(right).Style=xlBorders
            .Borders(top).Style=xlBorders
            .Borders(bottom).Style=xlBorders
        End With
        m=m+1
    End While
Loop
End With
```

3.2. To establish a drawing model of influence lines
The influence line drawing worksheet model is established as shown in Figure 3, in order to make loading transverse distribution coefficient calculation programming designing convenient, influence line vertical scale of each beam should be read from sheet2, better not use each vertical scale directly in sheet2, at the same time, the abscissa data is also needed, because of B being unit width1, each corresponding loading position abscissa from left to right in order is 0.00, 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00. After data model is established, the influence line can be drawn by taking use of XY scatter diagram in excel. The read-write programming design for vertical scale of each girder influence line is simple, it will not be repeated here.

3.3. To establish a calculation model of the load transverse distribution coefficients
After finishing drawing influence line, we need establish loading transverse distribution coefficient calculating model, as shown in Figure 4, the nine loading position influence line vertical scales of each girder can be directly quoted from sheet4, the data is as shown in black frame in Figure 4. For the loading need, proper columns are inserted between the nine loading positions, in order to input the specific loading position of vehicle wheels when doing practical loading [8], considering the width of sidewalk maybe within 2B, or beyond 2B, two sidewalk loading position are set in each side. When we import the loading position (wheel position) data, we should divide the distance from wheel loading position to the left side of the board (the position where abscissa is 0.00) by the real value of B, then type them in, input negative value in the column of sidewalk to the left of position where abscissa is 0.00. We should set apart rows for inputting loading position of each girder, the vertical scale of crowed loading position is calculated by Excel VBA programming, including the vertical scales of crowed loading position, and calculate the loading transverse distribution coefficient, due to limited space, we can’t give all Excel VBA procedure code.
4. Conclusions

After establishing Excel model for calculating loading transverse distribution coefficient with G-M method, combining Excel VBA programming designing function, we can get things done once and for ever, when we use it, we only need to input a few simple data to get the loading transverse distribution coefficient directly, no need to do fussy calculation or checking charts, so plenty of time are saved, at the same time manual computation error can be avoid. This method has the advantages such as strong practicability, intuitional and quick, convenient when being used to design beam bridges.

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Figure 4. Worksheet for calculating load transverse distribution coefficients.