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"Development of the Movable Bridge Balance Program"

by

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ABSTRACT

Florida Department of Transportation operates and maintains about 100 movable bridges with an average age of 34 years. Great need for balancing and maintaining the existing and new bridges demands a user-friendly and flexible computer aided system to substitute the exiting pioneer movable bridge balance process. The newly developed **Movable Bridge Balance Program** has two major advantages. It provides user-friendly, Windows based, interactive interface as well as detailed, transparent calculation in MathCAD. It can virtually calculate generic data for most movable bridges, provide optimal balance option and test suggested balance options. The editable Mathcad files enable engineers to accommodate special design needs.

This paper includes theoretical aspects of bridge balancing, the development of the Windows-Mathcad version of the **Movable Bridge Balance Program**, as well as hardware and software requirements.

INTRODUCTION

1997 Florida Department of Transportation (FDOT) inventory shows that the department operates and maintains 101 movable bridges with an average age of 34 years. Thirty-four of these bridges have been in operation for more than 40 years. Rehabilitation needs are urgent.

Ninety-five movable the bridges are bascule type, where the opening leaf is balanced by the counterweight so that the center of gravity of this rotating part is at, or near, the axis of rotation [1]. Trunnion-type, roller-type and hydraulic-driven bascule bridges are illustrated in Fig.1 through Fig.3.

Costly refurbishment necessitated by the wear out of machine elements in the drive systems of bascule bridges have provided impetus for minimizing unnecessary loading of machinery. Balancing the bridge regularly is very crucial in movable bridge maintenance.

Unbalanced torque of a movable bridge results from friction, wind load, angular acceleration as well as weights of the leaf spans and the counterweights. Accumulation of paint, dirt, and other materials also leads to unbalance.

In the past, leaf balancing of trunnion-type bascule bridges in Florida has been accomplished by motor current, torque measurements using wrench, and span drift measurements [2]. Rebalancing is achieved by means of movable weights added to or removed from counterweight pockets. The latest technique involves use of strain gages or pressure gages. Continuos recordings of drive shaft torque can be made on the final pinion drive shaft, using strain gages or pressure gages, during both opening and closing without interrupting the routine operation on the bridges [3].

With the advanced computer and data-acquisition technologies, the method of balancing introduced in this paper is a clear improvement over the exiting techniques. The purpose of the **Movable Bridge Balance Program (MBBP)** is to provide the tools for testing the balance of movable bridges on a regular basis and for performing rebalance calculations.

ANALYSIS

Detailed derivation of torque as a function of the strain gage readings for trunnion and roller type bascule bridges was presented in reference [4] and concluded as following.

For trunnion-type bascule bridge, assuming two driving shafts and the final shaft is instrumented, the torque as a function of the strain gage reading is given by,

$$T = \frac{10^{-3}\pi(\frac{R}{C_1})(C^4 - C_0^4)\gamma}{C} \quad \text{ft} \cdot \text{kip} \tag{1}$$

The factor multiplying γ in equation (1) is the Mechanical Factor, in which R is the radius of the rack; C_1, the pitch radius of the pinion gear; C, outside radius of the final driving shaft; and C_0, the inside radius of the final driving shaft. If an intermediate shaft of radius C is instrumented, it is necessary to introduce an additional factor equal to the gear ratio (greater than unity) between the final shaft and the instrumented shaft.

For roller-type bascule bridge, assuming two driving rollers and the final shaft is instrumented, the torque as a function of the strain gage reading is given by,

$$T = \frac{10^{-3}\pi(\frac{R}{C_1}+1)(C^4 - C_0^4)\gamma}{C} \quad \text{ft} \cdot \text{kip} \tag{2}$$

The factor multiplying γ in equation (2) is the Mechanical Factor, in which R is the radius of the rack; C_1, the pitch radius of the pinion gear; C, outside radius of the final driving shaft; and C_0, the inside radius of the final driving shaft. If an intermediate shaft of radius C is instrumented, it is necessary to introduce an additional factor equal to the gear ratio (greater than unity) between the final shaft and the instrumented shaft.

In hydraulically operated bridges, pressure gage or strain gage measurement at the cylinder can be converted into forces. Therefore, the expression for the torque as a function of the driving force of the hydraulic cylinder can also be derived as,

$$T = FH_t \cos\theta \quad \text{and} \quad \tan\theta = \frac{H_b \sin\beta + V_b \cos\beta - V_t}{H_b \cos\beta + V_b \sin\beta - V_t} \tag{3}$$

in which, θ is the angle between the leaf and the hydraulic cylinder, which is a function of the opening angles, β; as well as (H_t,V_t) and (H_b,V_b) are the coordinates of the cylinder top and bottom hinges respectively.

Note that in equation (1) through equation (3), γ, F, and θ are functions of opening angles and in the **MBBP** program raw data are being treated with root-mean-square numerical curve fitting to a cosine curve, since,

$$T = WL\cos(\alpha + \beta) \tag{4}$$

where α is the angle of the center of gravity at closing [5].

It is assumed that the above measured torque is mainly torque from weights and friction and the friction torque at opening and closing at a particular angle are the same. The weight torque is, thus, the average of the opening and closing torque. Although theoretically it is desirable to have a zero weight torque at all angles, in practice, bascule bridges are maintained slightly toe-heavy at closing for safety reasons.

Two methods are introduced in the **MBBP** program in choosing the balance solutions. They are NAB method and CORR method. The NAB method derives the most optimal combination of two weights at two given locations. For most bridges with asymptotic behavior, this solution could mean a close to ideal solution, however it might not be practical, since there might not be enough counterweights to be removed or big enough pocket space to add desirable counterweights. On the other hand, the CORR method provides the balance result with any suggested locations and weights, up to maximum of five combinations. Details can be found in references [4] and [6].

The Movable Bridge Balance Program

The **MBBP** program has a Windows-based, user-friendly interface as shown in Fig. 4. It includes FILE, BRIDGE NAME, MEASUREMENTS, BALANCING PROCESS, OPTION, VIEW, and HELP menu bars. The FILE includes conventional file management functions. The BRIDGE NAME includes bridge reference information. The MEASUREMENT allows for choices of bridge type, inputs for mechanical and electrical factors, and connection with any data acquisition system. The suggested system cost is approximately \$3500. The BALANCING PROCESS provides choices of balancing methods and finishes with the balancing task. The OPTION and VIEW take care of the configuration and operation needs. The HELP provides comprehensive design, application and operation details of the program.

To avoid black-box effect, which would be the case when the above mentioned calculations are introduced into the C++ program, all of the engineering calculations in this program are presented with MATHCAD. The transparency of the program is obvious as well as any special design need may be accommodated.

Overall, for movable bridge balance purpose, basic hardware and software requirements are a PC with a 32-bit operating system, MathCAD and MBBP.

CONCLUSION

The MBBP program provides a refined solution for movable bridge balance problems, thanks to the rapid development of the computer and data acquisition technologies. Inclusion of the hydraulic-driven bascule bridge balance procedure is well adjusted because of the increasing number of hydraulic-driven bridges. Refined mechanical factor forms; Windows-based, user-friendly, interactive interface; engineering calculation transparency with MathCAD; and advanced DAQ adaptability really makes this program unique in the bridge engineering industry.

REFERENCE

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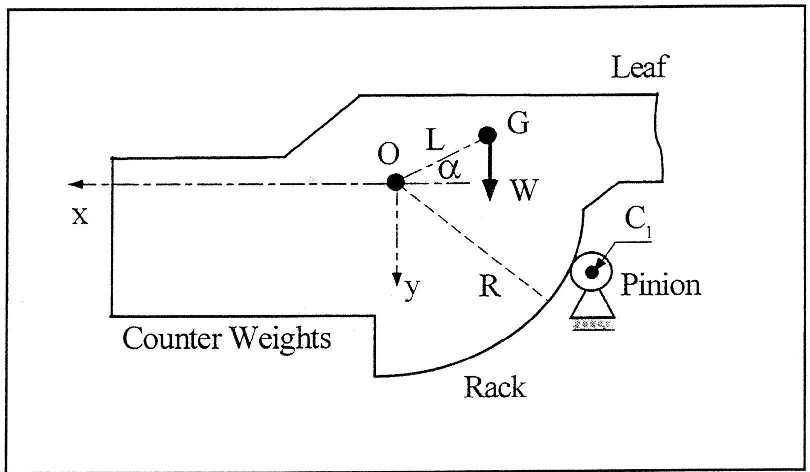

Fig.1 Schematic Illustration of a Trunnion-Type Bascule Bridge

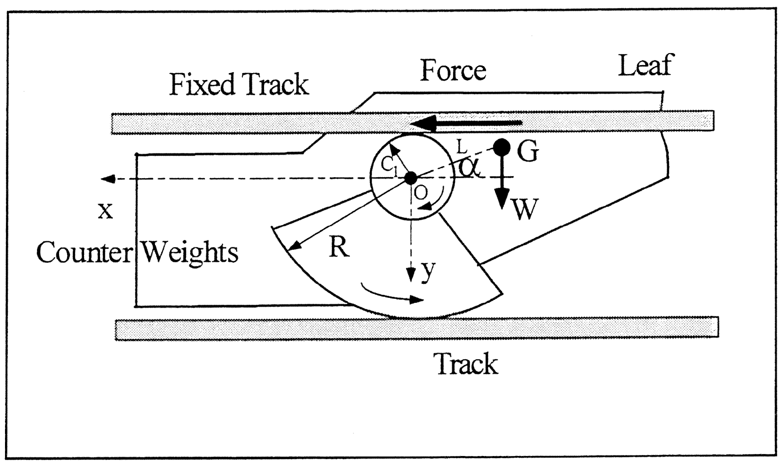

Fig.2 Schematic Illustration of a Roller-Type Bascule Bridg

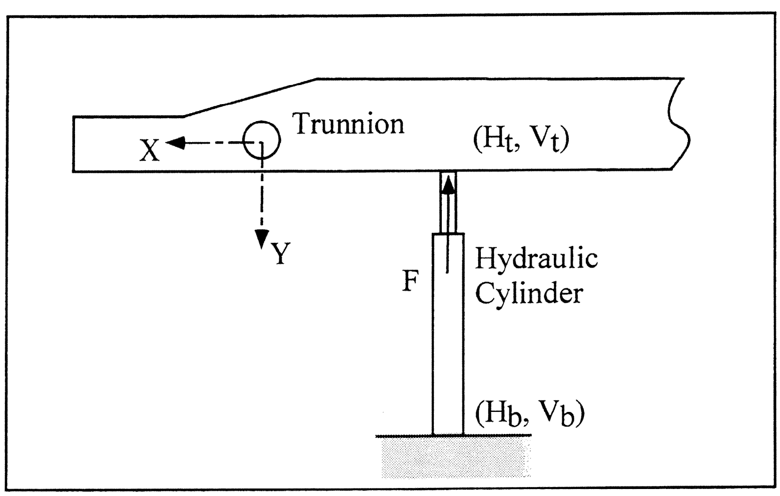

Fig.3 Schematic Illustration of a Hydraulic-Driven Bascule Bridge

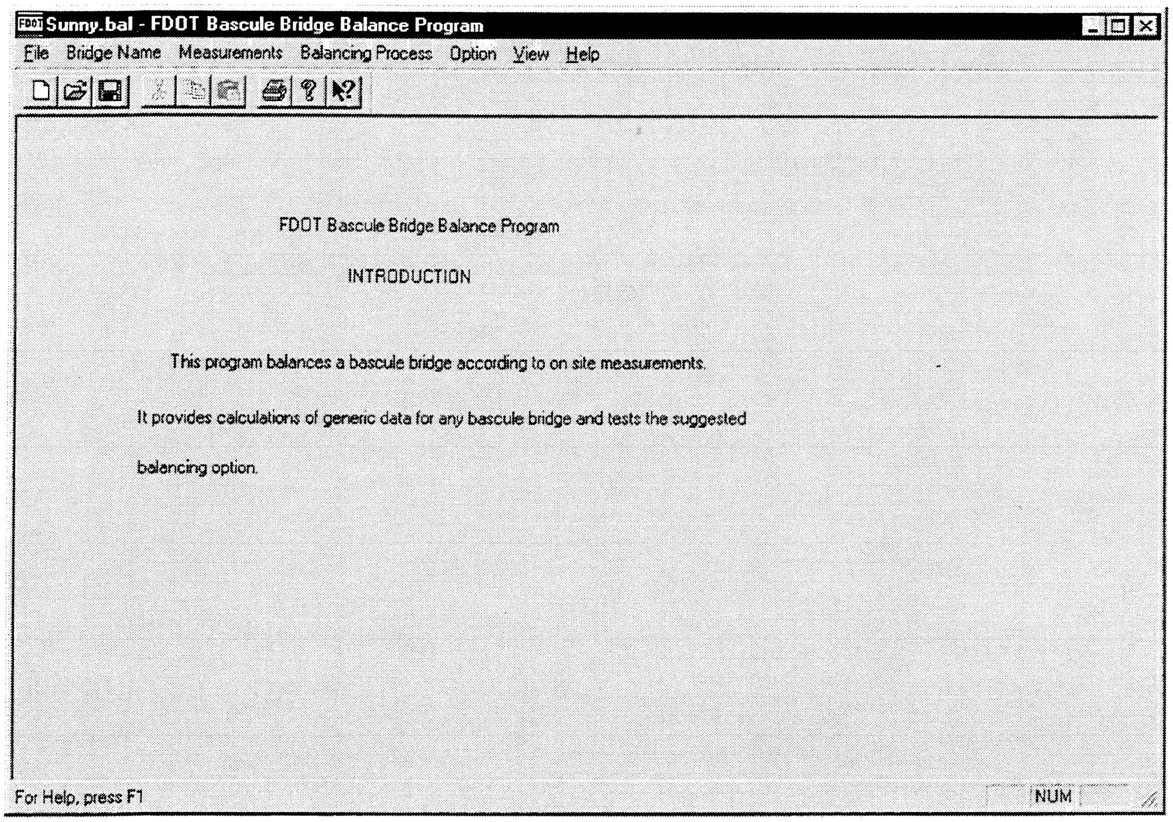

Fig.4 Example Interface of the Movable Bridge Balance Program