Bridge Engineering Automated Vehicle Application
B.E.A.V.A

Model and road geometry

Influence surface generation

Critical load pattern and generation

Research Engineers Limited

VERSION 1.3
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1. **Introduction**

The general philosophy governing the design of bridges is that, subject to a set of loading rules and constraints, the worst effects due to load application should be established and designed against.

The process of load application can be complex as governing rules can impose inter-dependant parameters such as loaded length on a lane, lane factors and load intensity. To obtain the maximum design effects, Engineers have to try many loading situations on a trial and error basis.

This leads to the generation of many live load application instances and a large volume of output data that has to be combined with dead load effects as well.

In view of the above, a computer program has been developed to minimise the load application process while complying with national code requirements.

Users can avoid the trial and error approach and eliminate any possible errors arising from inaccuracies associated with it.

The program is based on the use of influence surfaces, which are generated by STAAD.Pro as part of the loading process. An influence surface for a given effect on a bridge deck relates its value to movement of a unit load over the area of interest. The influence surface is a three-dimensional form of an influence line for a single member.

STAAD.Pro will automatically generate influence surfaces for effects such as bending moments for elements, deflection in all the degrees of freedom of nodes and support reactions. The engineer will then instruct the program to utilise the relevant influence surfaces and, with due regards to code requirements, optimise load positions to obtain the maximum desired effects.

Once the influence surfaces have been generated, they are saved and can be used for any further investigation that may be required. This will remain valid as long as the user has not altered the structural model. Changes to the structural model can alter the pattern of the influence surfaces and the user must ensure that a further run takes place before any further processing.

The Engineer’s knowledge and judgement is critical in deciding which effects are required and at what position to obtain them. This is where users can save a lot of processing time and also, can ensure critical positions are not missed.
2. General Description

The Current version of Bridge Engineering Automated Vehicle Application (B.E.A.V.A.), version 1.1, supports the UK BS5400 part2 code and the American AASHTO standards. All the relevant code instructions for loading definitions and traffic lane calculations are incorporated in BEAVA and in cases where vehicle axle arrangements are not standard, it is possible to define a vehicle and save it in the library for use it in the analysis. BEAVA is fully integrated in STAAD.Pro and utilises the same GUI for all input and output data.

The user defines the width of the Carriageway as straight or curved parallel lines, BEAVA then automatically calculates the following in accordance with the selected code:

- Number of Notional Lanes (Traffic Lanes)
- Influence lines along the centre line of notional lanes
- Loaded length along the Lanes
- Critical location of uniformly distributed load
- Critical location of knife edge load
- Critical location of vehicle load
- Maximum effect value
- Associates effects values

Once the program has completed calculating the above, a text file containing the results is displayed on the screen; as the user can then start examining the results graphically. Loading arrangements for the effects requested can be displayed on the model and, for every loading arrangement produced, the user can instruct the program to generate a STAAD.Pro load case.

The added live load cases can be combined with dead loads in the normal way of STAAD.Pro load combination generation.

The final model can then be analysed in STAAD.Pro and then post-processed.
3. Program Installation

Program installation is automatically carried out as part of the STAAD.Pro installation; there are no additional installation procedures to follow.

For STAAD.Pro installation instructions please refer to the STAAD.Pro Getting Started manual.

Also, please note that BEAVA is only available with release 2001 of STAAD.Pro and not with any previous releases. If your current version is not release 2001 you will need to reinstall STAAD.Pro version 2001.
4. Copy protection

STAAD.Pro comes with a copy protection device in the form of a hard lock.

The device must be inserted in the parallel port of your computer and must remain there during the entire duration that you are in one of the STAAD.Pro component programs.

For more information on copy protection device please refer to the STAAD.Pro Getting started manual.

Please note that if your hard lock device does not support the bridge loader module you will not be able to use it. In this case the option is greyed out from the menu and will not function.
5. **User Requirements**

BEAVA is an additional module to STAAD.Pro and is intended to work with structural models that are generated using STAAD.Pro. It is therefore imperative users are familiar with the model generation and analysis procedures of STAAD.Pro before they can proceed with efficient use of the bridge-loading module.

If this is not the case, please follow the Getting started and Examples manual in order to obtain the basic knowledge in the use of STAAD.Pro.

Further, it is essential that engineers who fully understand the analysis data and have knowledge of the loading code use this program.

Although every effort has been made to ensure the correctness of these programs, Research Engineers will not accept responsibility for any mistake, error or misrepresentation in or as a result of usage of these programs.
6. Program Operation Overview

There are a number of distinct stages in the use of the program.

To avoid inefficient use of the program, it is recommended that the following steps be taken in the order suggested.

- Create the structural model including member properties and support conditions.
- From the Mode menu select Bridge Deck Preprocessor; note that if your security device is not programmed for this module you will not be able to proceed. The menu bar has been modified to show Deck and Vehicle.
- Select the elements/members that define the deck area of the model.
- From Deck menu select Create Deck to define the deck.
- From Deck menu select Influence Surface Generator. This will start analysis procedures to create the influence surfaces.
- From Deck menu select Define Carriageway and define either a straight or curved carriageway.
- From Deck menu select Load Generator. Proceed to select the required input, on completion select OK. The loading program in now engaged and will calculate all the required loading arrangements that leads to the max/min effects you have requested. On completion a text file will be displayed on the screen containing the loading arrangements, which you can now display graphically.
- For each effect requested display the loading arrangements and examine the correctness.
- For each effect requested select Create Loading in Staad Model from Deck menu.
- After all load cases have been created, from Mode menu select Modeling and return to carry on with other load generations and combinations.
- Proceed with analysis and post-processing in the normal way.

The next sections illustrate the above in detail.
7. **Deck definition**

In order to apply traffic live loads, first the part of the model that carries the traffic loads, referred to as the ‘Deck’, must be defined. Deck definition in BEAVA is a very simple task. User decides which elements to include in the definition and selects them in the normal way. Deck names are user defined and may be identify sections within the model.

There may be more than one Deck defined per model as explained below.

**a) Single Deck**

Single deck definition is often adequate to carry out analysis of most bridges. Avoid multiple deck definition whenever possible, it can affect code dependent parameters and also increase processing time. However, when the use of a single deck definition is not adequate make sure you are familiar with the code requirements affecting ‘Lane Factors’ etc.

Deck definition for a simple bridge model is illustrated below.

Assume model of a bridge is as above and the deck is the top surface shown in green. From the menu bar select *Mode/Bridge Deck Preprocessor*
Bridge Deck Preprocessor mode is dedicated to all bridge load generation tasks and has three menu items, *Deck, Loading and Vehicle* added for this purpose.

Change the select mode to Plates, and then select the plate elements in the normal way. From the menu select *Deck/Create Deck* and either accept the default name, Deck 1, or change it if you wish.

Please note that decks must be defined form a continuous set of selected elements, avoid breaks as shown below.
b) Multiple Decks

Single deck definition may not be adequate to reflect the analysis requirements of certain bridges/structures that carry traffic loads. In order to overcome such analysis limitations, BEAVA allows multi deck definitions and also the option to process them individually or in groups.

It is very important to be familiar with the implications of multi deck analysis, loading codes for bridges do not address such issues in detail.

Multi deck definition follows the same procedure as single decks, you simply repeat it as many times as the number of decks you wish to define.

Some examples where you may need more than one deck follow.

In this case you may decide to select the curved section separately or all as one deck.

In the case of multi level bridges there may be no choice other than defining more than one deck.
8. Influence Surfaces

a) Introduction

When designing any part of a structure, one must place the live loads such that it will cause the maximum effect for the part under consideration. These effects may be moments, shear or support reactions. We also note that a particular load position that causes maximum moment at a section will not necessarily cause the maximum shear at the same section.

The relationship between critical effects and corresponding load position and other considerations have lead to the construction of influence lines and surfaces.

To illustrate the concept, consider a simply supported beam with a concentrated load placed transversely on the beam.

When the load is fixed in position, each section considered along the beam will have different moment and shear values. Also, if the section is fixed theses values will change depending on the load position.

We have introduced three variables; load position, section location and the effect under consideration.

To simplify, let us isolate the effect to bending and fix the location under consideration to be mid-span of the beam. Also, assume a unit load travels from one end of the beam to the other. The variables have been reduced to just the load location and we can now produce diagrams to represent bending values at mid-span as a function of load location along the beam. The resulting diagram is the bending moment influence line at mid-span of the beam.

It is clear that influence lines are very useful tools for analysis of bridges, which are subjected to the action of moving load systems.
However, in order to use influence lines effectively, it must be extended to cover two-dimensional surfaces in a similar manner. To this end, BEAVA has been developed to generate influence surfaces automatically once the 'Deck' or 'Decks' have been defined.

**a) Grillage analysis**

Often bridges are modelled with a grillage of intersecting beam elements that determine the general behaviour of the bridge under moving loads.

Modelling limitations and other considerations pertaining to grillage analysis are explained in textbooks that address bridge analysis; in this manual we shall limit our study to influence surfaces for grillages.

Assume the bridge has been modelled with a simple grillage as shown and that the Deck is defined as shown in red.

Generating the influence surfaces is now a very simple task.

From the menu bar select *Deck/Influence Surface Generator.*

BEAVA then proceeds with the generation of all the influence surfaces that the user may require during analysis.

For grillages, these are all the nodal deflection, beam end forces and support reactions.

Please ensure that prior to influence surface generation the model has been tested and runs successfully with a simple test load case.
Once the generation is complete, from menu bar select Loading/Influence Diagram and proceed to display the influence surface diagram for any of the above effects at the location desired. In this case mid-span moment has been selected as shown.

The influence surface is shown in isometric view.
Similar to influence lines, the vertical lines represent the values of bending moment for the mid-span, however, it is now possible to study the effect of loads with respect to transverse as well as longitudinal locations.

The section taken along the centre beam shows that in this case the influence diagram is similar to the simple influence line for the beam used in the introduction. Differences arise as a result of transverse members contributing to stiffness of the model.

The colour code on the left indicates the level of magnitude as the load approaches the centre of the model.

The scale used is always normalised to 100 and is for display only.
As illustrated in the following example, simplicity of the influence surface is very much dependent on the Deck definition and may get complicated with the introduction of inner supports, skew decks and releases at member ends.

Deflection Influence Surface at an inner span node.

The fact that, regardless of complexity, influence lines/surfaces have the same function and characteristics, rapid analysis of simple and complex models can be carried out with great accuracy. With out their use, such analysis would be extremely time consuming and prone to error.
b) **Finite element analysis**

More accurate analysis of bridge structures can often be accomplished with the use of plate elements. The fact that deck area of bridges or structures that carry traffic loads forms a continuous two-dimensional surface, it is appropriate to use plate elements to determine its response under loads.

As with grillage analysis, modelling limitations and guidance using plate elements are not covered in this manual, users are advised to ensure they are familiar with finite element analysis if they intend using it.

Influence surface generation is identical to that of grillages. To illustrate, a finite element model of a simple structure, with a Deck definition that includes all the elements is used.

The influence surfaces are similar to stress contours that are used to illustrate stress variation under a particular loading system.

Typical deflection influence surface for mid-span node is shown that illustrates the similarity.
Again, it is very much clear how the deflection is governed by the load position.

As expected, induced deflection at mid-span node increases as the load approaches it from either end.

It is important to use a fine enough mesh so that accuracy is not lost, this is a modelling requirement that applies to influence surface generation as well and must be observed.

More complex models give rise to influence surfaces that are not as predictable as the one illustrated, however, it is prudent to study the surfaces so that pattern of response can be established before embarking on load generation.

Further, one has to examine the quality of the influence surface in light of particular Code requirements and ensure adequate accuracy exits to guide the loads towards critical areas of the Deck.

You can see how span supports can change the influence surface sensitivity to lateral movement of loads.
Support reaction influence surface at inner span support.

A more complex deflection influence surface demonstrates that critical load positioning can be a very complex and time-consuming task.

c) Combined analysis

Most bridge models utilise plate, beam and other element types. As we are only interested in the area where loads are applied, i.e. the Deck, it is adequate to include only those elements that would complete the definition.

It is not often the case that a mixture of elements would be required to define the Deck, however, in this case BEAVA allows mixing element types and the procedure is the same as before.
The following example is just to demonstrate a Deck that is a mixture of plate and beam elements.

The influence surface shown is a combination of the two forms demonstrated earlier.

Also, you may wish to include overlapping elements in the Deck definition, this is illustrated in the following example.
So far we have confined influence surface displays to the Deck area of the model. However, BEAVA covers all parts of the model for any effect you may wish to investigate. The Deck area defines the live load application boundary with respect to which effects within the structure are calculated.

The following influence surface is for vertical support reaction away from the Deck area.
9. **Carriageways**

Once the Deck area has been defined the boundary of live load movements must to be provided so that code requirements pertaining to load application may be imposed.

‘Carriageways’ are defined to address this requirement and the following examples demonstrate different types available in BEAVA.

a) **Straight Carriageways**

To demonstrate Carriageway definition, the Deck area shown in red is used.

From the menu bar select *Deck/ Define Carriageway* and then press *New* to start.

To assist Carriageway definition plan area of the Deck, drawn in grey, also appears in the definition dialog box. Straight Carriageways are defined form left to right and must be confined to the boundaries of the Deck.

BEAVA assumes Carriageways extend the full length of the Deck in the direction of load travel and displays it accordingly.

Two pairs of X and Z coordinates for origin of curbs A and B are required to establish the start location and width of the carriageway. Also, if necessary, you may alter carriageway direction by providing an angle measured in degrees clockwise from the global X-axis.

As with Decks, where the running surface is divided by obstruction you may define as many carriageways as required, however, do not overlap and be aware of Code load factors.

To illustrate, a 9m wide Carriageway has been defined in the following example.
Once the carriageway has been defined it can be edited or new ones add in the same manner.

Notional or traffic lanes are placed within the carriageways and BEAVA calculates the widths according to selected loading standard. The standards use different names to refer to the same definition and to avoid confusion specific terms are used when addressing the standards in detail later in this document.

Note that ‘Spacing between points’ controls the stepping increment BEAVA uses to position loads at critical locations. It defaults to 0.3m and may be reduced to increase accuracy.

Once the carriageway definition is complete press OK to have it displayed on the model.
b) Curved Carriageways

Similar to the above procedure curved carriageways can be defined on either curved or straight decks. However, to demonstrate the input parameters the following curved deck is used.
The same menu selection that defines straight carriageways would address curved as well, however, on the dialog box select the ‘Curved’ tab as shown.

The values used in the above have defined a carriageway 11m wide as shown on the curved deck.

Centre global coordinate: X=0    Z=60
Kerb A Start:     Radius =59     Angle -45
Kerb B Start:     Radius =48     Angle -45
Direction of travel: Anticlockwise

Spacing between points: 0.3 m

c)  **Custom Defined**

If the aforementioned carriageway types are not applicable, ‘Custom’ type may be used to define the carriageway layout.

However, in this case, ‘Lanes’ making up the carriageway must individually be defined in ‘Sections’. Sections may either be Straight, Curved or Custom, added together in sequence to complete ‘Lane’ definitions.
It is best to demonstrate Custom carriageway definition with the aid of an example.

In the following example, the Deck has a straight carriageway and a Custom one. The Custom carriageway has one Lane 4 meters wide and the Lane has two Straight and two Curved sections.

The Straight carriageway is defined in the normal way, illustrated earlier, to define Custom carriageway, select the Custom tab as shown.
The input data and the display are for the Straight Section.

To add the first Curved Section, press the ‘Add Section’ button and then change section type to ‘Curved’. This will bring up input fields pertaining to curved definition and input values shown define the first Curved Section of the Custom carriageway.

There is an option to select which side of the Section is kerbed and also, delete Lanes or Sections that are not appropriate.
Two similar steps would complete the Lane and Carriageway definition.

In cases where the Custom Carriageway has more than one Lane of similar definition, the Lane can be copied to the left or right, otherwise, each has to be defined individually.
10) Load Application

Once the Deck has been defined, influence surfaces generated and Carriageway layout established load generation in BEAVA becomes a very simple process.

Various national loading standards, such as AASHTO LRFD or BS5400, provide rules that govern both load definition and application. Often the load definition is a combination of distributed and vehicle loads of varying magnitude and geometry. Further, application rules with respect to carriageway geometry can be different.

BEAVA provides a number of different standards to select and comply with, also vehicles that do not comply with standards can be defined and used in load generation. However, it is important that rules and guidelines of standards are understood before deciding to depart from them.

For now, a simple example is used to demonstrate load generation in BEAVA and later standard specific requirements are explained in more detail.

Assume, in the following example, we are interested in obtaining critical load distribution that produces maximum deflection at inner-span centre.

This is node number 16 and the Carriageway is defined as shown.

From the menu bar select *Loading/Load Generator*, the load request dialog box appears with the ‘General’ tab active as default.

This tab allows the User to select the loading Design Code to comply with and what kind of limit state, if applicable, to generate loads for.

The Decks tab permit the users select which decks to be considered in the calculations, and the other tabs are for the effects requested.
Select ‘Node Displacement’ tab and fill in the fields as shown.

Pressing the OK button will initiate the run and produce the loading pattern that would result in maximum negative deflection at node 16.

First display of output is a text file that contains all the loading information pertaining to the effects requested. Details of the content will be explained when specific loading standards are addressed, a typical result file is as shown.
The load distribution and lane divisions are automatically calculated and may be displayed graphically for each set of calculations.

Finally we can convert BEAVA’s loading patterns to Staad.Pro loads case by simply selecting, from the menu bar, Loading/Create Staad Model, this will generate all the load cases with corresponding headings for each load case.

This entire process will be demonstrated in much more detail when compliance with loading standards is explained.
11 Vehicle Library

BEAVA has a built-in library of standard design vehicles that are used together with other loads and rules of application to establish critical loading regimes. However, these standard vehicles do not cover all possibilities and therefore a vehicle definition routine has been provided so that users can define non-standard vehicles and use them in load generation.

To define vehicles or see details of standard vehicles, select from menu bar vehicle/Database.

The vehicle definition dialog box is as shown.

'Vehicles' lists all the standard and user defined vehicles in the database, 'Vehicle Data' shows the current units, front and rear clearance to other load types, overall width of the vehicle and axles details.

'Positions' sets the axel to either be fixed or variable in position. Fixed type do not change position in user-defined increments, however, they can have different fixed positions.

In the above display, third axel is of type 'Fixed', however, it can have five different positions.

You can view vehicle details simply by highlighting it in the list or define new ones by clicking the 'New' button.

Standard vehicles and their details are explained later in relevant sections.

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