3 CHAPTER III

BASIC THEORY

3.1 Masonry Structure

Historical building comes in various forms and geometries, such as pillars, arches, vaults, domes, and minarets (Jäger & Bakeer, 2010). Not all building can be categorized as a historical building. Each country has its own standard to determine which building can be categorize as historical building. The main aspect is it must be exist for at least than 50 years and represent or has particular implication for a history, certain religion, or a nation. The most common form of historical building is masonry structure.

In general masonry structure is composed of block units connected by mortar joints or blocks units directly intact without mortar (dry joint), which obtain its stability by the contact between block-mortar joint interface or block-block and friction among each other (Giordano et al., 2002; Pérez-Aparicio et al., 2013). Type of constituent that formed the block units and mortar joints are diverse. Constituent of masonry structure called as quasi-brittle materials is vary, raging from stone, brick, adobe, and other natural material (D'Altri et al., 2020; Lourenço, 2002; Lourenço et al., 2011; Mendes et al., 2020; Roca et al., 2010). While the constituent of mortar joints can be clay, bitumen, chalk, lime (cement based mortar), glue, and another adhesive material (Lourenço et al., 2011).

Masonry structure is distinct from the modern structure and most of the elements are non-homogeneous, furthermore the masonry structure display peculiar features such as low tensile and shear strength, high specific mass, lack of box behaviour, and low ductility (Lourenço et al., 2011; Peña et al., 2007; Roca et al., 2010). The non-linearity of the masonry structure is the consequences of the contact between the constituent of the masonry structure which cause the analysis become complex (Kassotakis et al., 2020; Lourenço, 2002; Pérez-Aparicio et al., 2013; Psycharis et al., 2019; Roca et al., 2010). Most of historical masonry structure does not equip with proper reinforcement, hence it is able to withstand gravitational loads but vulnerable if subjected to exceptional actions as an example is an earthquake.

Due to this exceptional actions, masonry structure exhibit cracks and partial or full collapse even in the moderate excitation (D'Altri et al., 2020). Since the behaviour of masonry structure under seismic excitation is different from the ordinary building, the evaluation of masonry structure requires particular procedure and method (Lourenço et al., 2011; Peña et al., 2007). Many factors need to take into account in analysing the seismic behaviour of masonry structure, such as the material properties, the geometry of the structure, the joint or connection between each blocks, and the structure condition itself (Lourenço et al., 2011).

Analysis of masonry structure especially those which categorize as the historical properties encounter several difficulties. Most of the historical masonry structures are exist since hundred even thousand years ago, hence limited data resources are available and require the laboratory test or parametric study. Obtaining mechanical behaviour can be conducted using laboratory test, however the non-destructive in situ testing, adequate laboratory testing and numerical methods must be conducted. Furthermore, important aspects for generate the masonry structure analysis are missing, for instance (Lourenço, 2002) :

- the geometric data of the masonry structure is not available;
- the detail information until the inner structure about the masonry structure is not complete;
- the wide variability of mechanical properties because most of the historical masonry structure was made using natural materials and workmanship;
- due to long construction periods, most of the core and constitution of the structural element occur significant changes;
- no record and report about the construction process and sequence;
- the existing damage sometimes emerge in unknown event;
- mostly current regulations and codes are not applicable for analysing the historical masonry structure.

3.1.1 Modelling of the Masonry Structure

Modelled masonry structures could be conducted in various approach. The main concern in modelled the masonry structures is the joint, which cause the weakness of the plane and source of material non-linearity (Lourenço, 2002). Modelling approach used depends on the level of accuracy and the simplicity or refines that required in the investigation study (Lourenço, 2002; Mendes et al., 2020; Sutcliffe et al., 1999). According to (Lourenço, 2002; Sutcliffe et al., 1999), there are three modelling approach can be conducted, namely detailed micro-modelling, simplified micro-modelling, and macro-modelling. Detail illustration is depicted Figure 3.1 to present better understanding about the differences of modelling approach.

Detailed micro-modelling emphasises on the separate model for each element where the block units, mortar, and the interface are modelled separately, therefore this type of modelling also called ‘two-material approach’. Continuum elements are represented by the block units and mortar in the joint, while the discontinuum elements are represented by the block units-mortar interface. Since each element modelled separately, this modelling approach is considered as the most refined approach, hence leads to more accurate results. Despite its refinement, high computational effort needs to be conducted and major cost will be needed in order to modelled the structural details.

On the other hand, in simplified micro-modelling the behaviour of the mortar and the block unit-mortar interface are lumped into a common element and become the discontinuum element. At the same time, the expanded block units are represented as the block units and continuum elements. Since some properties in the model is lumped into a common element, this modelling approach cause the accuracy reduced. Hence, this modelling approach categorized as the intermediate refined approach.

The last modelling approach is macro-modelling which is considered as the least refined approach because there is no distinction between induvial block units and joints, and assume that entire block units, mortar and the block unit-mortar interface are homogenous continuum, hence this approach also called as 'equivalent-material approach'. Despite its un-refines, this modelling approach is applicable and more convenient for modelling large masonry structure. But still, it is not suggested to capture the detailed stress analysis of the masonry structure.

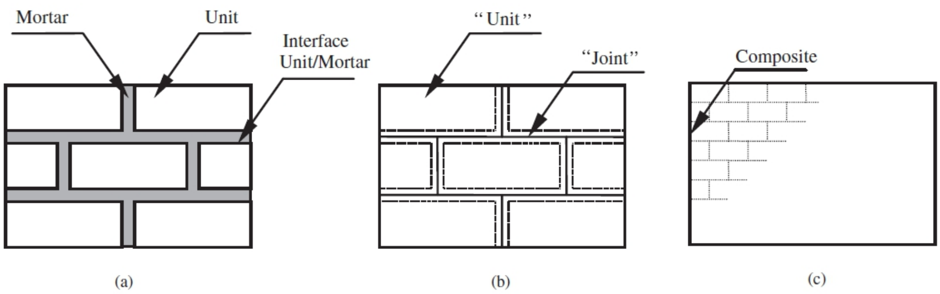

Figure 3.1 Modelling strategies for masonry structure: (a) Detailed micro-modelling, (b) simplified micro-modelling, and (c) macro-modelling (Lourenço, 2002)

Masonry structure consists of numerous unit, depends on the type of the masonry structure. Simple masonry structures such as stone arches or stone columns which consists of countable number of unit could be simulate fully and individually for each unit. However larger and more complex masonry structures which consists of numerous units are rather challenging if using the same approach as the simple masonry structures. Simulating each unit individually considered as impractical solution to be handled.

The important aspects in modelling the masonry structure is which model will be suitable to simulate in order to obtain the realistic closest result. Due to the complexity of the structures, to simplify the structures need full consideration in order to achieve the realistic closest result. The more detailed the modelling of the masonry structure, it extremely demanding for the computational work, but it is obvious that the result may generate the realistic closest result (Roca et al., 2010). Although its complexity to generate large element of the structure, most author suggest the use of the micro modelling because the result is more reliable than the macro modelling (Giordano et al., 2002; Lemos, 2007).

As an addition, generally modelling the masonry structure and analysing it using micro modelling in three-dimensional models require tremendous computational skill and resources which rather difficult to obtain, therefore, some author prefer to perform the complete dynamic analysis in two-dimensional model(Peña et al., 2007).

3.2 Mortar Joint in Masonry Structure

Joint in the masonry structure, especially for the ancient masonry structure can be categorized into two types: mortar joint and dry joint. Mortar joint is the common type of the masonry structure where blocks are stacked to each other then mortar joint is grouted for the filling. While the dry joint does not need any mortar material for filling the empty spaces since each block connect perfectly as depicted in Figure 3.2.

Figure 3.2 Mortar joint and dry joint masonry (D'Altri et al., 2020)

The bond between masonry block and mortar joint is very weak, therefore cracks and failure of the masonry can be formed in the block itself, however mostly it appears along the bond or mortar joint, nevertheless it depends again on the strength of the block and mortar joint itself (D'Altri et al., 2020; Idris et al., 2009). Mortar joint that filled the empty space in vertical and horizontal section of the block called as head joint and bed joint, respectively as mentioned in Figure 3.3 (Shadlou et al., 2020; Vemuri et al., 2018).

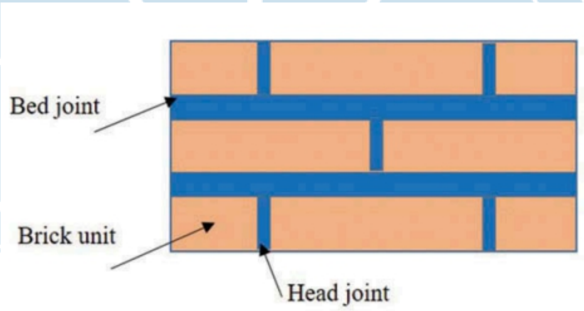

Figure 3.3 Head joint and bed joint (Vemuri et al., 2018)

There are five basics failure modes of the joint that commonly occur as describe in Figure 3.4. Those failures are direct tensile cracking of joint, sliding along bed or head joint, diagonal tensile cracking of units, compressive failure due to mortar dilatancy and cracking of units in direct tension (D'Altri et al., 2020; Shadlou et al., 2020; Sutcliffe et al., 1999). From the figure, the failures concentrated at the weak joint mostly to occur are (a), (b), (c) and (d). While for the (e) mostly to happen in the brick unit. According to (Shadlou et al., 2020), the failure possible to occur due to the combination of shear, tension, and compression loading.

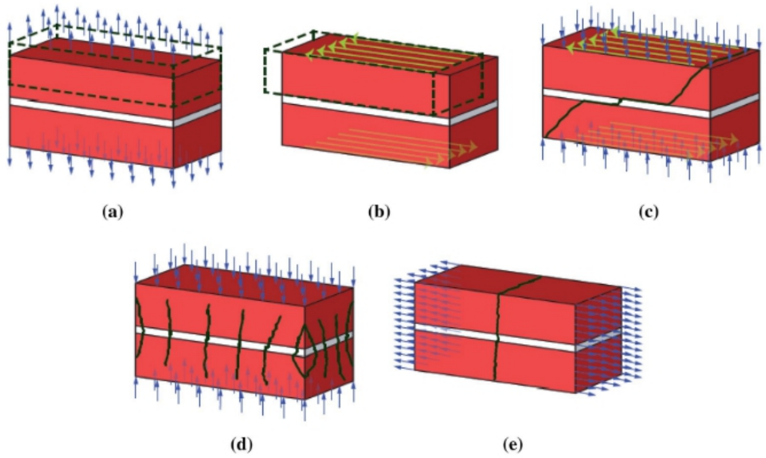

Figure 3.4 Modes failure of the joint: (a) direct tensile cracking of joint, (b) sliding along bed or head joint, (c) diagonal tensile cracking of units, (d) compressive failure due to mortar dilatancy and (e) cracking of units in direct tension (D'Altri et al., 2020; Sutcliffe et al., 1999).