Seismic Behaviour of Double Arched Tunnel: A Review

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Abstract

Major earthquakes will cause multi-hazard issues for tunnels. Yet, advantages associated with it in terms of sustainability, time, land and fuel saving have made tunnels a vital option in modern cities. Double-arch tunnels are generally accepted for their effective and economical solutions as they have significant advantages in adjusting to the characteristics of the region and environmental safety. Experimental, numerical and analytical studies had been conducted by the researchers to understand its static and dynamic behavior. In the present study, authors have categorized and critically summarized the researches on double arch tunnel. It is essential for platform of higher research and development in this field.

Keywords: Double Arch Tunnel; Seismic hazard; Stability; Safety analysis

1. Introduction

The tunnel is under the constraint of the surrounding rock in a three-way stress state, and the seismic efficiency of the tunnel is higher than that of the ground structure [1]. However, significant damage to the tunnel occurs in every major earthquake. Considering the role of underground lifelines there is a need to give more attention to these structures in these modern developed societies where living conditions are increasingly dependent on the complex network of lifelines [2]. The present world is going for development in full swing but considering the environmental factors everyone is looking for the sustainable development. In recent times, with the swift economic development of a country with higher traffic requirements, the number of expressway lanes has increased. For which tunnels like double or multi arch tunnel have become need of the hour. However, single tube tunnels and triple tunnels had been studied by researchers under different loading conditions [3-5]. In addition, behaviour of jointed rock-mass also plays significant role in geotechnical structures [6-8]. In the critical structure, such as tunnels or any underground structure, it makes very useful use of space in mountainous regions, which have an effective advantage in utilizing distinctive terrain conditions and environmental sustainability [9]. Thus these double arch tunnels save times by making distances shorter which in result declining the fuel usage of vehicles contributing to of pollutions. Since the start of underground tunnels, safety problems in tunnel construction have received much interest [10]. A significant number of operating tunnels, indeed, have different security issues resulting from the design constraints of geological conditions and other factors [11]. Considering all the aspect in the modern times, double arch tunnel is more efficient as well as economical as it can adapt to different terrain condition as well as environmental conditions. Double arch tunnel can be used for complex route in mountainous areas [11]. Compared to the ordinary tunnel, the key advantage of the doubly arch tunnel is that a central wall links the two adjoining tunnel. [12].

Double arch tunnel is being studied by many researchers so far and they have studied about the methods of construction for all these double arch tunnels [13]. They have studied about the materials of the tunnel whether it consists of rock, soul or both. They have about studied about the additional materials like foam concrete, fly ash and concrete used in lining for seismic analysis of the tunnel. The damping effect of foam concrete on significant properties of tunnel is studied by means of an experimental test and computational simulation in the dynamic analysis of the double arch tunnel. Different experimental tests using model and prototype are studied to know about the seismic resistant capacity of these tunnel and those experimental results were compared with numerically simulated software [14-15]. Many scholars have evaluated about the behaviour of voids on the double arch tunnel. Some researchers have explored the structural characteristics of the double arch tunnel under the impact of void spaces mostly on the central wall. Effects of surrounding rock pressure, load distribution are also studied. Stability of the middle wall is a very important aspect in the double arch tunnels which have been studied with various methods by researchers. Jae Kook Lee et al [12] have estimated rock load which is of utmost importance in multi arch tunnels using stress variable method and compared it with other method like Tarzaghi’s rock mass classifications and rock mass rating (RMR). Chan Liu et al have researched the laws on...
acceleration reaction of shallow buried doubly arch tunnels by experimental and computational simulation means.

Lining in a double arch tunnel controls the smooth operation of the underground structure. Xu Zhang et al. examined in detail the influence of voids in the lining on the failure of the symmetrically arched tunnel. The analogy for evaluating the adjoining rock stress of the symmetrically shaped tunnel was formulated by many findings gathered on the symmetrical numerical model [16-18]. The adjoining rock thrust is described as the weight on the supporting structure due to the deformation of the adjoining rock following the excavation work [19]. The parameters of the adjoining rock were assessed by researchers using three-dimensional numerical modeling software [20]. The surrounding rock parameters have significant impact on the efficacy of tunnels due to different loading operations [21-27].

As the double arch tunnel is a critically complicated underground structure, a careful observation of the deformation and internal forces in it is necessary. The morphological identification, the evolution phenomenon and the skewed influence of a double-arch tunnel under various subterranean conditions were studied [28]. An important analysis of tunnel structures' response to dynamic loads has also been carried out. Researcher like Huang et al. 2009 has taken train load as dynamic load. Many researchers have studied about the construction method considering various geological predictions and by taking the strain stress relationship for the stability [29]. To study the stress strain distribution during construction mathematical modeling was first introduced. Liu Tong et al. have studied in detail about the deformation or stability loss during the construction of multi arch tunnels and they said about safe measures to be adopted. With the construction of highways going on large scale in the country so many tunnels in different geological and morphological conditions are needed to be constructed [30]. Researchers like Liu and Chan have studied the complex situation where rain and underground water problem occurred [31]. In this review paper, behaviour of double arch and multi arch tunnels under various conditions related to seismic effect as well as various safety factors have been studied carefully using all the previous research works and study.

2. Materials used

2.1. Rocks

Since most of the double arch tunnels are constructed in mountainous regions so rock plays an important role for the research purpose. Many researchers have studied and found the materials used for the double arch tunnel in their research are found to be rock of various classes. These classes of rocks are used in the surrounding rock as well as in the tunnel itself. The rock classification has a very important role in estimating the rock load of multi-arch tunnel. Rock and their type have been studied properly to know its effects on the seismic stability of the tunnel under static as well as dynamic condition [32]. Stress strain values of rocks, their deformability, plasticity and elasticity has been studied carefully. All the methods to classify rocks like Tarzaghis’s method, Rock Mass Rating (RMR) has been taken into consideration for estimating the properties like surrounding rock pressure and rock load and over burden pressure on the tunnel. Mechanical as well as physical properties of rocks have been studied carefully by researchers [11]. The impact of underground flow of liquid in rock is of utmost importance regarding the safety of tunnel which has been taken into consideration while studying the influence of seepage flow on the surrounding rock by Li Xi-Bing et al. [31]. So taking all points in consideration all the properties of rocks whether it geological, physical or mechanical it should be well studied while designing the double arch tunnels for their seismic as well as general stability.

2.2. Soil

Soil and its properties have been studied by the researchers in their study of double arch tunnel as well as multi arch tunnel. Voids and effect of void on the safety, seepage analysis and earth pressure has been closely monitored by them. Earth pressure shows extinct characteristics for the seismic effect and soil structure interaction. Mechanical properties are used in the model prototype and various laboratory tests like static triaxial test is used to study the impact of voids on the failure of symmetrical as well as asymmetrical double arch tunnel [34].

2.3. Concrete and other materials

Materials like cement mortar, fly ash, barite powder etc. are used for lining in the model as studied by researcher like Hui Yang et al. High strength concrete of foamed nature prepared fly ash and cement with definite proportion by weight is used for adjoining rock. Model boxes used in the test are laid on thick gravel
filled with sand and the inside wall of the prototype is adhered to a thick polystyrene and polyvinyl chloride film. These all materials have a very important role in the study of dynamic response, acceleration response and seismic response for the shallow as well as buried double arch tunnel. Concrete plays an important role in the study of crack propagation of the middle wall and the spandrel of double arch tunnel [35]. The internal displacement of adjoining rock, axial forces in anchorages and other forces were studied for the tunnel having steel. [36].

3. Construction of Double Arch Tunnel

The Modern Austrian Tunneling Method is the most common technique used in the making of doubly arch tunneling among all construction methods of tunneling. Due to its economical and versatile construction mode, NATM has become a common form. Drilling and blasting techniques are conducted in NATM tunnel excavation and rock bolts and shotcrete liner are used as the primary support device in NATM [36]. This rock bolts and shotcrete liners operate on continuous support to manage stress as well as deformation stabilization of the adjoining rock mass and support system that helps in the design and excavation of tunnels. NATM needs dynamic observation of geological conditions of the excavating face of the tunnel and the performances of supporting structures [37].

Construction techniques such as the three heading excavation method widely used for rocks of lower class rocks, and the central heading excavation technique commonly used for better Class like III class rocks, are used in the construction of a double arch tunnel. The other design techniques such as pilot drift method, middle pilot hole stage technique, were also studied by the researchers.

Each building technique has its own characteristics. Sidewall arch feet stabilization is in advance to monitor the deformation of underlying rock in Three Pilot Drift Processes. Compared to other techniques, the economy of this process is low and it is acceptable for the fragile surrounding rock. The economy is best suited to the middle pilot-hole stage process. Due to its one-sided support in columns, the first support is simple to get a sink and bending. It is best suited for hard rock [38].

Double arch tunnel serves a lot of advantages in the modern infrastructure world but there is matter of serious concern in the construction of these double arch tunnels because it carries with it some typical disadvantages such as cross section span of excavation is large and ration of rise span is small. So basically the support and excavation is a bit more complicated in the double arch tunnels than the single ones. Therefore it is a matter of serious concern in studying the construction methods as well as the construction process which will help in attaining the seismic stability of the double arch tunnel. The basic difference of double arch tunnel with ordinary tunnel is that, the two tunnels in this type of tunnels are connected by a middle wall, whose stability also affects the tunnel's stability [39-43]. So, it is very important to choose such reasonable method which favours the stability of middle wall and tunnel as well as other parts of tunnel. The common construction methods studied here consist of two stages. The first steps involved in the common construction methods of double arch includes the excavation of middle drift which is filled by middle wall after the assurance of getting support for the middle drift. Second, when the partition wall achieves certain strength, the left and right tunnels are excavated. The center diaphragm method (CD), section method and bench method are typical excavation methods for left and right tunnels.

In the course of constructing the doubly arch tunnel using the FEM, scholars simulated the bench method [12] – (Gao et al) and under various construction techniques, the mechanical reaction characteristic of the bench system on the underground structure is derived from this method. By sub-sectional method morphological development in the tunnel pressure arch is analyzed. The CRD process research was undertaken in depth for the exploration of the low submerged double arch tunnel [45-46]. Even after so many researches based on the stability due to construction method of tunnel has been done in past but so far the influence of these methods have not much an impactful research on the stability of wall connecting the two arch tunnel. In order to obtain guidance for the selection of the double arch tunnel, a study was carried out on the ultra-shallow buried doubly arch tunnel with large span in which the failure law and the stress characteristic of the middle wall between the CRD technique and the double-sided drift technique were compared and analyzed in the excavation of underground structure [12]. Therefore, the construction of tunnel is a very important aspect in the stability of double arch tunnel. Whatever the method is adopted for the construction, it needs to be stable against deformation, stress, and overburden pressure of surrounding rock. Researchers in the present world have used simulation for construction process using 2D and 3D FEM model as well as XFEM model as per the requirement.
4. Methodology

4.1. Experimental work

Many research studies are concentrated on the experimental findings and these experimental data are further used in simulation for the comparative analysis. Scholars have used shaking table test to know about the dynamic response, seismic response, acceleration response, cracking failure of lining, displacement response, deformation analysis and effect of damping layer on these responses. The experimental test also helps to identify the seismic reaction of a tunnel which is double arch in nature with a damping as well as without a damping layer under symmetrical and unsymmetrical pressure. The shaking table test is also used for the analytical comparison of the shallow and buried double arch tunnel, and the shaking table test is often used to study the biasness of the tunnel[1-2].

Experimental test using physical model of required dimension is conducted to find the mechanical behaviour of the central wall tunnel under the effect of void behind the lining as well as without voids. For the assessment of ground strain, internal forces and lining breakdown, the model used in the experiment is used. It also offers a comparative study of the symmetrical and asymmetrical double arch tunnel. In order to determine the distorted pressure characteristics of the equivalent load in the double arch tunnel, an experimental and numerical analysis of the self-adjusting arching properties under the rock tension surrounding the tunnel is performed [11].

4.2. Experimental study on seismic behaviour and stability.

For their experimental observation of these properties of the double arch tunnel, researchers used the "shaking table test" to analyze the dynamic response, vibration reactions, seismic response, and deformation and stress analysis of the double-arch tunnel. This test was completed in the laboratory of the multi-functional shaking table. Hui Yang et al. have used the shaking table and physical model is shown in Fig 1 and have used the parameters of the shaking table test discussed below in table 1 [1].

| Parameters                  | Values                              |
|-----------------------------|-------------------------------------|
| Size of table               | 4mx4m                               |
| Maximum load                | 30 tonnes                           |
| Applied frequency           | 0.1-50Hz                            |
| Maximum displacement        | X and Y direction= 250mm, Z direction= 160mm |
| Maximum acceleration        | X and Y direction= ±1.0g, Z direction= ±1.6g |

The experiment used a gravity-distorted model to determine the seismic performance of the double arch tunnel. The similarity ratio of the model used in the experiment is determined using factor like geometric size of the shaking table, material used to make the model. The other similarities like acceleration and density are also derived using similarity theory. The internal measurements of the rigid box of model used in the experiment are 3.5mx1.5mx 2.1 m and at the bottom of the model there is thick layer of gravel of thickness 4 cm and medium sand is used to fill the pores to find the dynamic responses of double arch tunnel. A layer of fine stone is used at the bottom and pores are filled with fine sand to fill the pore of model box in case to determine the seismic response laws under unsymmetrical pressure with damping layer [44]. The base of the model box is protected from relative slipping of the bottom of the middle box during vibration while assessing the acceleration reaction law of the low submerged double arch tunnel. The base of the model box is manufactured as a resisting boundary.
4.4. Mechanical Behaviour of double arch tunnel

To determine the role of voids on the mechanical behaviour of tunnels which are of double arch type, physical model test experiments have been done. Leung and Meguid have examined the effects of loss of contact of earth pressure distribution on the lining. The model test program comprised of a loading system and a structural loading frame made up of Plexiglas plates and a metal frame of steel. Polytetrafluoroethylene film was glued to the inner portion of the load cell for smoothness between the field and the steel plane. Hydraulic jacks, pressure sensors and rigid metal plates were present in the loading system, which can have a total capacity of 300 kilo Newton. The similarity ratio is adopted as per the similarity theory in these model tests. During the test, the internal forces, structural breakdown and process of failure were observed. Model test comprises of three steps: construction of model, installation of measurement instrument and the last one is loading process [45-46]. After using the entire steps one can determine the mechanical behaviour of the central wall in double arch tunnel under the effect void behind lining.

4.5. Analysis of testing results

All the parameters found during the shaking table responses be it acceleration response, dynamic response or seismic response are analyzed [1]. Boundary effect, earth pressure, displacement and internal forces and stress responses has also been analyzed. The acceleration amplification factor which is termed as AAF is often used to determine the acceleration response law while analyzing acceleration data. Using AAF, acceleration response law is determined under varying loading direction and different excitation direction [47-49]. Comparative analysis of acceleration response, seismic response, stress response, biasness of tunnel, stain response is taken into account while doing shaking table test experiment. The role of foam concrete used as a damping layer in seismic research is studied and how it influences the stabilization of the tunnel.

As per the acceleration response law, the lateral acceleration reaction of the symmetrical points is significantly varying where the horizontal plane is considered the same and the vertical center line of the central wall is treated as symmetrical axis. The acceleration which is vertical is also found to be different between the foot of the arch and the spandrel [44]. Under the vibrations of seismic activity, the acceleration amplification factor shows a somewhat distinct configuration, which reveals that the acceleration response of is greatly influenced by the path of the incident seismic wave.

4.6. Numerical simulation for shaking table test

Most of the research studies on double arch tunnel have been based on numerical simulation. Even the results obtained from experimental tests and model test are compared with the numerical simulation [50]. A numerical model is made and it is analyzed with different software. In our paper we have found that the data obtained by shaking table test, the physical model test to find mechanical behaviour of tunnel is further compared with numerically simulated data. In all the studies and researches done regarding seismic behaviour and stability of tunnels a series of FEMs were used that were constructed using different software according to the need [50-52]. Few researchers have also incorporated the extended finite element model for the study of progressive failure of lining models [11]. The two dimensional numerical analysis has also been conducted by researchers using general non-linear finite element code [34]. Displacement functions which were discontinuous in nature were
implemented in the XFEM for the purpose of rupture approach in the context of their notion of usefulness partition.

Numerical simulation method has been used to determine structural analysis of the central wall of tunnel which is double arch type, where stress, strain, displacement analysis have done through the simulation process [53]. Numerical simulation method is of so much importance in the present progressive world that from the process of excavation of tunnel till the safety analysis of the tunnel, it is always used for the analysis. Using 3-D numerical simulation tools, a dynamic tunnel modeling program is established to model the construction activities of double arch tunnel. Landslide which is a major point of concern regarding the safety of tunnels during excavation has also been studied using numerical simulation. During its excavation, Zhang et al. modeled the circumstance of a landslide in a multi-arch tunnel [35]. The coupling impact of the effective stress and seepage area in the pressure arch of the double arch tunnel was studied, especially for the water-rich strata. Scholars have analyzed the magnitude of the pore pressure of the underlying rock under varying drainage conditions. The software used in the numerical simulation by researchers for the double arch tunnels are MIDAS GST NX, ABAQUS, FLAC\textsuperscript{3D}, ANSYS [24].

4.7. Numerical model

The numerical model is made using similarity ratio based on the physical and mechanical characteristics and time parameters using different softwares for the simulation [16-18]. The similarity ratios of stress, strain, geometry, displacement and internal forces are selected considering the condition of equipment used in the test. The size of the model is determined and the model is categorized into the many elements as per the software used in the numerical modeling the strata above the double arch tunnel are specified about the material. For minimizing the boundary effects in double arch tunnel the magnitude in terms of size for the computational model should be greater than five times bigger the physical model size as found from the study Chen Guo-Xing [54]. On the basis of that it is decided about the restraining condition on the side of the model whether it will be fixed or free on any side. Some simplification and assumptions regarding the properties of surrounding rock mass and the number element used for meshes in the numerical model is defined in the three dimensional numerical model. To simulate cracking behaviour of the lining in double arch tunnel, the extended finite model was adopted while doing the 2D numerical simulation.

5. Study of Seismic Behaviour of Double Arch Tunnel

5.1. Acceleration Response

The acceleration reaction under the effect of varying intensities and different direction of the earthquake wave excitation is analyzed after comparative analysis of an experimental test done by shaking table test which is further analyzed by computational simulation. Effects of bias and non-bias of shallow submerged double arch tunnel have been identified [1]. Acceleration amplification factor also referred as AAF is used in the study for the acceleration response laws. It is found that the horizontal AAF of the hole which is bias has $\cap$ shape while the hole of the tunnel which is non-bias has $V$ shape. In the experimental test and numerical analysis it is observed that the vertical AAF of the bias-hole first decreases and then increases continuously while the non-bias whole shows an increasing trending the vertical amplification factor. When both the hole is either bias or non-bias the acceleration response in horizontal direction comes to be less than in vertical direction. In such conditions the difference between the vertical and horizontal AAF comes to large in the double arch tunnel. A seismic wave incident path used during the tests has a higher impact on the response of the acceleration [46].

An unbiased tunnel is better as far as regularity is concerned as compared to biased one that’s why there will be a greater influence of acceleration laws in case bias tunnel. For double arch tunnel, the horizontal and vertical acceleration reaction is often different, regardless of the tunnel's state of bias. So whenever anyone design for the seismic structural support of double arch tunnel, one needs to keep this in mind about the difference in vertical and horizontal acceleration response. The result obtained from experimental data and numerical simulation which is quite similar [1-2].

5.2. Effect of damping layer on Seismic Response and Dynamic Response

Foam concrete is used as damping layer to assess the seismic reaction of double arch tunnel. After so many researches on the seismic reaction of double arch tunnel using experimental test and numerical analysis Hui Yang et al. have used damping layer of foam concrete to minimize the seismic and dynamic stability. The
acceleration and strain response under the effect of unsymmetrical pressure are analyzed under various seismic wave intensity levels and direction. The seismic wave which is directed incidentally will have a greater impact on seismic response. The invert, arch foot, and spandrel of the double arch tunnel have been found to be the poorest component in terms of seismic efficiency during the computational simulation of the finite element model [45]. Wang et al. commented by using 3D computational modeling that the seismic weak point is the central wall of the tunnel as well as its invert.

The damping layer is used to decrease the internal force of the lining under seismic load after discovering the weak seismic point in the double arch tunnel to maximize the earthquake resistance of the double arch tunnel [55]. Foam concrete layer has the ability to change the response peak of acceleration without changing the spectral features of the acceleration time curve. The peak tension and displacement of the weak seismic point of double arch tunnel can be decreased by using damping layer made of foam concrete. Since the internal forces in double arch tunnel is quite large in comparison to the rest of the tunnel and these forces play a key role in seismic reliability of the tunnel. The damping layer reduces the magnitude of these force thus helps in improving the seismic efficiency of the tunnel.

5.3. Effect of voids on the seismic stability of double arch tunnel

The voids that are present behind the double arch tunnel's lining regulate its stability. The voids have an effect on internal in the lining of the double arch tunnel in the shape of failure pattern, which is affected by the position and scale of the voids in the double arch tunnel's diameter. There are relatively few variations in internal forces due to the voids at the invert and middle wall. The bottom of the lining of the middle wall is considered as the vulnerable part and it suffered the most damages. The existence of the void behind the center wall of affects the redistribution of earth pressure, due to which there is a stress concentration on each the sides of void that is situated on the apex of middle wall which leads to initiate the crack emergences in the lining and excessive deformation which ultimately influences the operation of double arch tunnel leading to huge loss of economy [48].

The voids present at the top of the middle often disturb the mechanical behaviour of the double arch tunnel. The mechanical behaviour depends on two factors mainly size of void and the shape of the tunnel. As voids increase in size, the impact of voids on the double arch tunnel increases. The tunnels of larger diameter are more sensitive to the change in the height of voids than the tunnel with smaller diameter. As the impact of voids depends on the shape of the tunnel, the changes in the deformation and internal forces in symmetrical tunnel is distributed symmetrically unlike the asymmetrical tunnel. There is substantial decrease in the bearing capacity due to the presence of void. In an asymmetrical double arch tunnel the distribution laws of lining cracks are found to be more problematic than that of symmetrical double arch tunnel. In both symmetrical as well as asymmetrical the location of initial cracking is the same.

6. Effect of Rock Load on Seismic Multi arch Tunnel

The estimation of rock load is of major importance in constructing multi-arch tunnels. In traditional tunneling, sprayed concrete and installed rock bolts act as the typical rock load. As a result, concrete lining is added under the influence of earthquake load to counteract the water pressure in an undrained state. Rock mass classification given by Terzaghi and Rock Mass Rating is used by the researchers for the estimation of rock load. In the research paper, it has been estimated using 2D numerical analysis with the help of rock mass classification, construction step and overburden pressure. The estimation of rock load uses the criteria of stress variable method and the factor of safety [53].

A multi arch tunnel consisting of multiple tunnels has a structurally weak shape. The cause for the weakness is due to the fact that tunnel diameter is wider than the height of the tunnel. The excavation of adjacent tunnel affects the stress and displacement distribution in the outer edge of pre-excavated tunnel. Therefore, when constructing the concrete lining for the existing tunnel, it is important to take into account the rock loads generated due to the excavation of the adjoining tunnel. To investigate the rock load, numerical analysis method is more efficient for multi arch tunnel than existing empirical methods. Using numerical analysis, the estimation of rock load allows in establish an efficient concrete lining designs in deep tunnels. The anticipated rock load varies considerably with the phases of construction in the case of weak rock mass conditions. Therefore design and stability analysis of the multi arch tunnel must be done according to the steps of construction when there is a variation in rock load due to different rock conditions [39-43]. After the excavation of adjacent tunnel is completed, cracks rises at the shoulders of the middle tunnel which results in increasing the rock load and stress concentration. By using the reverse analysis it is found that the correlation between the deformation moduli of the rock mass and rock load height can provide better understanding into the behaviour of tunnel.
7. Research Gap

During the study of all the research and analysis done on double arch tunnel, we have found some critical points which needs to be discussed in future for further course of development.

- Among all the research paper none or very few have studied about the thermal stresses in double arch tunnel.
- There is minimal literature on the reaction of the double-arch symmetrical tunnel to voids at various locations.
- There is little awareness of the distinctions between symmetric double-arch tunnels and other tunnel forms with voids behind the lining.
- Less knowledge is available on the effects of voids at each point in the double arch tunnel.
- Limited literature is available about controlling or improving the seismic stability with modern technology of the double arch tunnel.

8. Conclusions

In recent year, with rapid development of technology there is an increase in the urbanization of countries where there is a very high requirement of traffic construction in the critical areas like mountainous region. To fulfill all these requirement double arch tunnel has become a very important critical structure which is being used mostly highway tunnel construction. Double arch tunnel has the advantage of occupying lesser land and has higher space utilization rate than other tunnel. Despite the remarkable advantage of double arch tunnel, it also faces a lot of challenges against its stability and safety. The safety aspects of the double arch tunnel have attracted researchers about its safety, stability and most of them have studied its seismic and dynamic behaviour.

- Double arch tunnel is more susceptible to seismic failure. To study that behaviour experimental, analytical and numerical simulation has been done to know about the seismic properties of double arch tunnel under seismic load. Most of the researchers have used shaking table test and compared their results with numerical simulation. They have found the error between two is very less.
- Use of foam concrete as damping layer has been studied and it is found that with the help of foam concrete damping layer the seismic performances of the double arch improves.
- Effect of voids in the mechanical behaviour of the middle wall of the double arch tunnel is studied and found that voids have an adverse effect on some parts of double arch tunnel like on invert and spandrel becomes the weak seismic point in the tunnel due to voids. Its effect is also studied for symmetrical and asymmetrical double arch tunnel.
- Rock load is estimated via various methods and its importance on the stability of double arch tunnel has been studied by researchers.

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