Review of the earthquakes caused by fracking the Fylde:

What happened? How did we get here? Where are we going?

WHY KEEP THE 0.5 LIMIT - WHAT ARE THE RISKS?

WHAT IS THE PROBLEM WITH THE REGULATORS?

Author: Michael Hill, B.Sc. C.Eng. MIET.

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Review and analysis of the earthquakes caused by fracking the Fylde: Why should the safety limit not be altered?

REVIEW HAS BEEN PREPARED BY MICHAEL HILL, B.Sc (Hons.) C.ENG. MIET, EXPERT MEMBER THE TECHNICAL WORKING GROUP ON HYDROCARBONS AT THE EU COMMISSION.

Following the recent earthquakes on the Fylde (some 30 between the period of the re-commencement of fracking on the Fylde until the operator appears to have decided to voluntarily shut down - approximately 15 days in total) there has been much hype and hysteria from certain sides; some justified and some not. This review looks at the history of how we came to be where we are, what actually just happened, the risks associated with that and where we are now heading. I will also consider two other areas that are crucial to the overall debate on fracking: the regulators and the risks.

The operator has clearly been unable to operate within the safety limits set back in 2011/12 following the previous earthquakes and has stated so publicly in the media. The public are very concerned at what has happened and the government have stated they will not raise the 0.5 Local Magnitude seismicity limit. This situation is now a head on collision of interests; public safety, political and financial. So either the limit is raised to allow for the commercial viability of fracking in the U.K. or safety will take precedence over financial considerations and the science and engineering that led to the introduction of the 0.5 limit will be respected. This might result in fracking being terminated in the U.K. after just two wells fracked and both stopped for the same reason: earthquakes.

SEISMICITY (EARTHQUAKES)

Firstly, it is important to understand how earthquakes are measured. Simplistically the magnitude (or Local Magnitude) is measured on a scale from 0-10. Values below zero represent very small seismicity. This allows for the power or energy of the quake to be established and is very useful for allowing comparisons with other quakes. In layman's terms magnitude measures the overall shaking ability of the earthquake.

However, another important measurement is the peak particle velocity (PPV) or intensity of the earthquake and this is very much location dependent. For example it is possible to have a relatively low magnitude quake, say 0.8, and yet for it to cause damage to buildings. It depends on the intensity of the quake at a given location. So if the 0.8 was near the surface and close to the foundations of a house or close to the cement of a fracking well then it could cause serious damage.

Magnitude is the metric that is most commonly used. It is a logarithmic scale. This means that for each increment of the scale there is a 10 fold increase in magnitude or shaking. An earthquake of magnitude 2.1 shakes 10 times more violently than a quake of magnitude 1.1. Equally a magnitude 2.1 quake shakes 100 times (10x10) more violently than one of magnitude 0.1.

So to raise the safety limit for fracking from 0.5 to 2 (i.e increase of 1.5) would not mean the power of the quake is 3 times more as you might expect (3 x 0.5 = 1.5). It is 32 times greater in power ($10^{1.5}$) and the energy released would be some 178 times more.

THE 0.5 SAFETY LIMIT

During the period from 2010 to 2013 the author met with senior civil servants and ministers at the Dept. of Energy and Climate Change (DECC), now the BEIS, to discuss regulation and monitoring with respect to fracking. In 2011 the earthquakes that were experienced on the Fylde (some 50 in all with two of them registering 1.5M_L and 2.3M_L) led to a full review of fracking and induced (by fracking) seismicity (earthquakes). Cuadrilla instructed de-Pater and Baisch to investigate.[(1)]

Their report concluded that it was most likely the fracking had caused the earthquakes and those quakes had significantly damaged the well over a considerable interval.

The author reviewed the paper as Fylde Borough Council Technical Advisor at the time and also discussed it at length with the DECC (Simon Toole and John Hayes M.P.) and with Mark Miller (then CEO Cuadrilla).

The review for the DECC by Styles et al also concluded that the earthquakes had most likely been caused by the fracking and recommended the safety limit of 0.5.

The author was invited to examine this limit with the DECC. I wish to make it clear I was not involved in the setting of it but did review the value with the government and have first-hand knowledge of the debate that took place around it. The 0.5 limit seemed too low to me, as in very hard to work within and senior civil servants agreed. However, after a long discussion and some mathematical modelling, it was agreed the limit should be set at 0.5.[(2)] The primary reason being considerably larger magnitude earthquakes can and do occur many hours after the fracking has ceased. **This situation and rational has not changed and still applies.**

So the government and the industry agreed in 2012 with the 0.5 limit and agreed it was necessary for safety. This is the history of this limit and it is strongly founded in science and engineering by seismologists and engineers.

Very important to the debate raging presently is the fact that the new CEO of Cuadrilla accepted the 0.5 limit and agreed it was set at that level to ensure safety. [(3)] For Mr. Egan to now plead in the media and push ministers for a higher limit is simply astonishing based on this earlier experience.

RE-START

Despite strong misgivings regarding the level of regulation and monitoring coupled with a totally inadequate emergency response strategy (in the author's opinion based on research with the Police, LFRS, HSE and LCC) [(4)] the government allowed fracking to re-start and this began on 15th October, 2018. Within 3 days of this the first earthquakes were being recorded by the British Geological Survey (BGS). Their webpage detailing the last 100 days of events demonstrates the issue clearly. Up until 18/10/18 there was not a single earthquake recorded in Blackpool. Post 18/10/18 98% of all recorded earthquakes in the British Isles are in Blackpool.[(5)]

The industry endeavouring to focus the media and public's eyes on "felt" seismicity. That is earthquakes that actually shake our houses and the ground beneath our feet. This is certainly a very real possibility should fracking re-start again after what appears to be a self-imposed hiatus by the operator following the 1.1 quake on 29/10/18. The risk of felt earthquakes becomes even greater should the government de-regulate the industry further and reduce the level of safety by raising the 0.5 limit. However, the risk at the moment is not to construction above the ground but that below it, miles below it, at the epicentre of these quakes: the borehole itself. We do not know the intensity (PPV value) at the borehole but It is immediately clear that the intensity at the wellbore must be greater, although the precise values are hard to determine with confidence. Just as in April 2011 when the well was severely damaged by two quakes of 1.5 and 2.3 M_L, this is a very real possibility now. We do not know. My own assessment would be that it is unlikely the casing is ovalized but the cement surrounding it; that could be different matter.

The cement surrounds the steel tubes inside the borehole (casing) and it fills the gap between the casing and the borehole wall – the actual rocks that have been drilled through. It is the only thing that is stopping (to date) upto 11.5 million litres of fracking fluid from vertically migrating up the side of the borehole. It can do this in the annulus between the cement and the casing and can move up to the higher areas and eventually the aquifer.

Why would fluid move upwards against gravity? I have been asked this question many times because the industry tries to confuse the public with what seems a "no brainer". The reason is twofold. Firstly it is understood by hydrogeologists that fracking fluids are less dense when compared to surrounding formation fluids and hence rise and secondly the pressures during and immediately after fracking are huge (in the range 2000 – 15,000 psi).

The fracking fluid will find the path of least resistance. Due to repeated and increasing energy earthquakes the gap around the casing and between the cement and the formation wall could well have increased. It is then very likely that is exactly where the fracking fluid will flow.

RISKS

In addition to well integrity risks detailed below there are a number of others which due to space constraints we cannot discuss further here other than to briefly state what they are. Fracking fluid that has become toxic and radioactive[6] through leaching will, over time, be able to migrate upwards to the aquifer using faults as effective escalators (horizontal migration). Interestingly, despite 3D seismic imaging we may not know about faults if they have not already provided 'significant' slip (i.e. it is the existing offset we image, new faults generally remain invisible[15]. The flare and silica sand has been shown, through mature studies in areas fracked around the world, to be a significant factor in increases in cancers, chronic health complaints and birth defects. Studies have also shown an increase in road traffic accidents, particularly head on collisions, through the restless actions of individuals tired of being constantly held up by fracking trucks. There is also the risks from spills (accidental or on purpose) of fracking waste (flowback) on our roads and fields.

WELL INTEGRITY

These two words the author has repeated over and over since 2010 and becoming involved in this fracking project. They are vital to protecting the environment and our health. Well integrity is a crucial mitigating factor – as in mitigating the risk to our health and our land from vertical migration (up the outside of the borehole) of fracking waste. Repeated earthquakes will lead to a deterioration of the cement. What seems small to us at the surface is not to the well as was shown on the first well fracked, PH1 in Weeton, Lancashire. The operator is stating they are checking and verifying well integrity after each earthquake. How are they doing this in a borehole 2 miles deep and 1 mile long? The answer is by monitoring the annular pressure but is this enough to protect us?

Annular pressure (AP) is a recording of the pressure between two annuli, in the case of oil and gas then between two casing strings. The author and Cuadrilla in the past argued very strongly about these APs and whether relying on them was a good idea. The author argued for more measures, particularly the use of cement bond logs as the well was being built. Well integrity is something that must be built in to a well at construction phase and is very hard to do much about after construction. Hard to detect and hard to fix. It can be done post construction but it is much more expensive. An AP is a very crude tool. It will indeed tell the operator if well integrity is lost but only at a crude level. By this I mean that an entire string of cement must have failed first before you will know anything. As you typically only have three strings in an entire well then this represents a very significant failure before you are aware of it. As the author understands it there could be leakage into the formations but not an entire cement string failed (complete pathway) and so the AP would not pick this up. So APs on their own are not enough to guarantee well integrity.

Additional measures such as pressure profiling with tight tolerance bands (and audited on site by the HSE) should be conducted after each break period when the pressure is reduced. Threshold pressures need to be recorded and monitored. Training on the habitualisation of risk needs to be reinforced. This is where it becomes "normal" to have repeated earthquakes and workers start to ignore what are in fact significant risks to well integrity. They "believe their own press" that all is fine, the AP says so and the procedures are working – so they think. In fact the opposite can be the case but you just don't realise it as you have alarm fatigue and become habitualised to the risk.

When you combine this with the "swiss cheese effect" where the holes rarely line up and so you think you are safe when in fact you are very close to a serious disaster (holes all line up) but just don't know it, then I believe this operator, in demanding a higher limit, is suffering from exactly the complacency described above.

So this is another reason why raising the 0.5 limit is not recommended. It is resulting from a habitualisation of risk and it will result in a higher seismic activity of a greater magnitude and so is highly likely to result in greater cement failure and even casing deformation. A loss of well integrity which the AP measurements might miss!

OTHER AREAS REQUIRING CLOSER EXAMINATION – THE REGULATORS

The vast bulk of work that the author has been involved in relating to fracking has been regarding the regulation and monitoring of the process. I have developed or contributed to a number of papers, briefing notes and articles that have been peer reviewed and published. These include a review of the Royal Society 10 recommendations [(7)], The Medact Report [(8)] and a piece in The Lancet [(9)]. All related to regulation and the regulators. The key players are the Health and Safety Executing (HSE) and the Environment Agency. Late to the party (because it was not in existence earlier) is the Oil and Gas Authority.

There is not space here to examine just how poor, in the author's opinion, the performance of the regulators, and in particular the Environment Agency (EA), has been. A lack of application and scrutiny coupled with a stock defensive position in response to any questioning seems to be the norm. One example to demonstrate all: the author witnessed Sir James Bevan (CEO of the EA at a public meeting 8th March, 2018 in Pickering), completely ignoring any questions/points put to him at all regarding failings of the EA to regulate fracking properly. Instead of answering a single important point he repeatedly stated his people were dedicated and he had full confidence in the EA regulating this industry. He failed to appreciate that the public had serious concerns and precious little confidence in the organisation Sir James was head of. Let's will use three examples of where they maybe failing us.

1. The EA have failed to answer, across two years, the simple question: according to the law (EPR2016 regs) and their own previous Chairman, Lord Chris Smith, "how can you guarantee not a single litre of fracking waste will not migrate out of the shale play"? There is, as of time of writing , already up to 11.5m litres of toxic and radioactive fracking waste under the Fylde. The EA permits, issued to the operator, relied solely on assurances from the operator that not a litre would leave the target formation – the shales.[(10)] That was before Cuadrilla found they could not work to within the 0.5 limit and caused some 30 earthquakes in two weeks. It was also before the then Technical Director of Cuadrilla contradicted the EA permits in public by stating they did not know where the final resting place of the fracking waste was. The author have asked the EA the question again and again and they have never given an answer. I made the same point directly to Sir James Bevan and no answer was given.

2. The EA have failed to properly understand and assess the risk associated with the permits they have issued to the operator regarding the recycling of flowback. When the author asked them in person what process was the operator using to enable safe reuse the response was no process had been defined and the EA would assess it closer to the time. I pointed out that it might be considered as bit premature to permit an operation (recycle flowback) that you have no understanding of and no knowledge how to regulate it. The EA confirmed in their latest bulletin [(14)] that the operator is indeed recycling flowback. A practice that has at times proven very difficult to achieve safely in the US.

   Further, in the same bulletin the regulator states "the low level seismic activity to date has all been within the range expected for fracking" and "Cuadrilla's own reports confirm no well integrity issues". The naivety of allowing the regulated to dictate to the regulator beggars belief but putting that to one side, this is a prime example of the aforementioned Habitualisation of Risk.

   To conclude that 30 BGS recorded earthquakes (including two they detail on the bulletin of 0.7M_L and 1.1 M_L) are normal and "expected" is exactly to fall in to the trap of normalisation. That the Shale Environmental Regulator Group (SERG) which is the HSE, EA and OGA, has become subject to normalisation is a very serious and dangerous escalation of risk. They go on to describe the situation as something "they knew would happen".

This is to play down the very real threats to the well and to "normalise" a very abnormal situation. One that is categorised as a RED event by the OGA – who are a member of SERG in the first place! This contradiction is alarming in itself and one can only speculate as to what pressure the regulators have come under to capitulate.

The EA state if there was a loss of integrity that could lead to contamination following a quake they would demand Cuadrilla stop. The problem is that they appear to have absolutely no understanding whatsoever of how to actually know whether there is a loss of integrity or not. "Cuadrilla's daily reports confirm there are no well integrity issues". They rely on the regulated (Cuadrilla) to tell the regulator (EA) that it is all "a ok"! It is astonishing and frightening in equal measure as our health, our food and our environment are dependent on them knowing what they are doing. The regulator refers to felt seismicity at the surface as a justification that the traffic light system is working. This fails entirely to appreciate that the well is likely to be "feeling" these quakes considerably more so than us and potentially compromising well integrity in a manner that the operator is not aware of. The EA have failed to understand that the borehole linking the shales and waste to the aquifer is the most likely conduit for contamination in the event of seismic activity.

3. The HSE, OGA and EA together published a document [(11)] on 30th October 2018 stating there has been no well integrity issues. The question has been asked just how after 30 seismic events they can state categorically that well integrity has not been compromised? No answer. The document went on to state the OGA is monitoring operations to ensure compliance with the hydraulic fracturing plan (HFP) including the earthquakes. It said "provided the event is in line with the HFP and the risk of induced seismicity is managed then operations may resume". The author has asked just how is it that earthquakes of increasing magnitude and quite astonishing frequency (as per BGS website) above 0.5M_L can ever be in line with the agreed HFP? No answer. The OGA confirmed just last year that the 0.5 limit "is greater than the level expected to be generated by fracturing rock" [(12)]. The author has asked how is it that the HFP can state it is "in line" to have quakes of 1.1 – pause for 18 hours, reduce the pressure and then crack on – which has nearly always led to a bigger event? How is this "managing seismicity"? No answer.

REVIEW CONCLUSION

The request to raise the limit appears from the operator's statements to be very much based on commercial viability. [13] This is not an acceptable reason and so should be refused. The operator must demonstrate that there is a safety reason for doing so or that safety will not be compromised in anyway. Bearing in mind the energy increase and that the previous well fracked by this operator (PH1) suffered a well barrier failure and significant damage over a considerable interval [1] with earthquakes measuring 1.5 and 2.3 then to raise the limit is clearly not in the interests of safety. To do so would pose a threat to the aquifer, agriculture and our water. The knock on effect on the Fylde's indigenous industries such as faming and tourism could be devastating and needs to be considered in an decision making process.

The present scenario being presented by the operator appears to be: we agreed to the 0.5 limit, we helped set it up, we thought we could operate within it, now we discover we can't, we do not understand why, so let's raise the limit so we can hit the formations with a bigger hammer and see what happens then!

The operator is complaining now in the media and to ministers that they are being "strangled before birth" and "we're are just about to choke" is hysterical language. Such language has no place in a sensible debate about a very important subject : real risk to public health and severe damage to the environment.

All events greater than 0.5 and within 14 days of fracking should be labelled as a RED event under the traffic light system. A red event is a red event regardless of whether fracking at the time or not. The present situation, playing down the so called trailing events (earthquakes that are recorded after the pumps have been turned off), is to falsely mitigate the risks through words rather than actions. The operator needs to take action regardless. The well will "feel" such events regardless. It is a red event and needs registering as such.

I think it is very clear to all, regardless of technical background, that to raise the safety limit has no basis in science, will reduce safety and could lead to a catastrophic incident. It must be refused by the UK government regardless of pressure. **Safety must always take precedence over commercial viability.**

The regulators should take responsibility for what they are responsible for and responsible to – us. In my opinion and experience they seem to spend more time and effort on how to shift responsibility to others. They must act now to avoid a disaster happening – that is their job – not after it has happened to try and "learn the lessons and make sure it never happens again".

In conclusion, as a Chartered Engineer, heavily involved in this topic for a long period, I feel it would be reckless to raise the 0.5 limit. To do so would be putting the public of the Fylde at even greater risk of severe damage to health and the environment than they already are. The 0.5 limit is there for a reason, that reason has not changed.

Michael Hill C.Eng. MIET.

7th November, 2018.

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3. Letters published between F. Egan and the DECC dated 1st November, 2012. Egan states "In conjunction with industry experts and your team at DECC we have developed a traffic light seismic monitoring and mitigation system. The traffic lights set for our fracking in Lancashire have, however, been set well below levels commonly used worldwide to ensure that we maintain a much larger factor of safety at this exploratory stage".
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16. This Briefing Note was reviewed by Professor David K Smythe, Emeritus Professor of Geophysics in the University of Glasgow, for geological accuracy and for engineering by a former well discipline director for a major oil and gas company.

AUTHOR

Michael Hill is a Chartered Electrical Engineer. He studied Electrical and Electronic Engineering at Loughborough University following sponsorship by Marconi Avionics Ltd. Mike worked in oil and gas as a wireline engineer and then as the engineer on seismic survey crews in the 1990s. He's now a director of a small engineering consultancy specialising in process automation of oil and gas rig equipment. Since March 2010 Mike has been researching regulations into onshore exploration and development.

He has written several papers on regulating shale gas and has also been published in local and national media including The Lancet, The Guardian and The Times. Mike has also worked on news articles with the BBC, ITV, Bloomberg, RTL (German TV) and the Dutch national broadcaster – NOS. He was a key contributor to The Medact Report on fracking.

He has consulted/advised/given evidence to: The Dept. of Energy and Climate Change (U.K. Gov.), The European Commission Joint Research Council , Office for Unconventional Gas and Oil, the local councils (FBC, WBC, LCC), The Royal Society, the UK Regulators (HSE, EA), NGOs (FoE, COOP, RAFF, EKAF, REAF, FFF), the British Geological Survey, The Churches in Lancashire Group and the industry. He has spoken at numerous conferences, Q&A Panels, public meetings, professional bodies and in the media. He lives in Lytham St. Annes, Lancashire, England.